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PRELIMINARY OBSERVATIONS ON A NEW DISEASE OF WHEAT AT ALLAHABAD

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(With two text-figures)

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ABSTRACT

A disease of wheat caused by *Alternaria tenuis* Nees has been reported from India for the first time. The pathogenicity of the fungus has been established by artificial inoculations. It has been suggested that *Alternaria* (which may be *A. tenuis*) reported from Indian soil acts as a facultative parasite on account of excessive moisture which lowers the vitality of the grain.

OBSERVATIONS

Certain parts of the United Provinces, including Allahabad, had unusual rain during March and April 1944: The various winter crops were nearly ready for harvesting and they suffered considerable damage on account of the untimely rains. Many plants of wheat fell on the ground on account of the accompanying wind, and germination of seeds started in some cases. The yield was further reduced on account of the falling of some seeds, many of which had either rotted or had developed small seedlings on the soil. The remaining grains of wheat, even when the plants had remained erect, were blackish in colour. This blackening was not confined to the grains only but was present on the glumes as well as on some of the sheathing leaves. The diseased grains showed different degrees of blackening. In some cases only a small tip at one end developed light discoloration, in others the colour was darker but the area was restricted and in still others a large part of the groove of the grain and its adjoining regions were involved. Certain grains, apparently healthy externally, showed some mycelium in their inner regions. Isolations from them also gave the same fungus which was present in seeds showing marked external symptoms of the

disease. A detailed comparison revealed that they differed from really healthy seeds because they had a light yellow coloration in the vicinity of the mycelium which was mostly confined to one end of the grain.

Fig. 1 shows the general condition of the grains and the various intensities of the disease. The size of the discoloured areas on the leaves and glumes varied considerably. A microscopic examination of the diseased areas

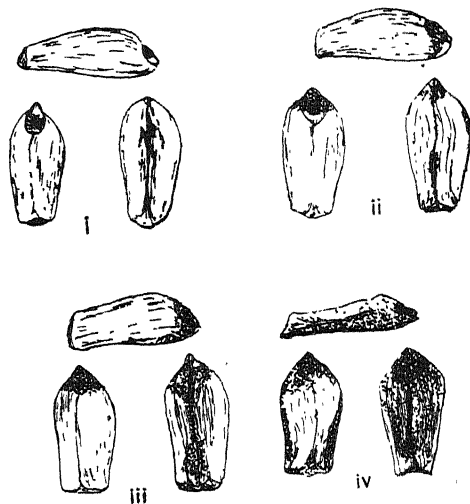


Fig. 1. Showing three views of each grain to indicate the full damage. The infected parts are shown by dots. Deeper coloration of dots indicates more severe attack. $\times 10$.

showed the presence of the spores of *Alternaria tenuis* Nees, associated with an olivaceous, branched, septate mycelium. Numerous examinations from different regions always gave the same result. The general structure of the mycelium and the spores is shown in Fig. 2.

The surface of the grains was sterilized by means of 0.1% mercuric chloride solution and they were then incubated in moist chambers. Pronounced development of the mycelium and spores was observed on the third day.

90% Alcohol served equally well for surface sterilization of the grains. Some surface sterilized seeds were placed on various synthetic media (Acid Agar containing 20 gms. Agar, 1000 c. c. water and a few drops of lactic acid; medium A of Asthana and Hawker containing 5 gms. glucose; 3.5 gms. KNO_3 , 0.75 gms. MgSO_4 , 1.75 gms. KH_2PO_4 , 20 gms. Agar and 1000 c. c. water; and Brown's starch medium containing 2 gms. Glucose, 0.2 gm. Asparagin, 1.25 gm. K_2PO_4 , 0.75 gm. MgSO_4 , 10 gms. Potato Starch, 20 gms. Agar and 1000 c. c. water) and similar results were obtained.

Single spore cultures of the fungus were prepared and its pathogenecity on wheat seeds was tested by the method described by Koch (10). Inoculations on moistened wheat seeds gave positive result and in advanced cases the grain was much damaged. It was noticed that symptoms exactly similar to those of the normal diseased grains could be produced by dipping moistened grains in a suspension of spores and then placing them on dry sterilized filter papers inside petri dishes. The organism could be re-isolated from artificially inoculated seeds after proper sterilization,

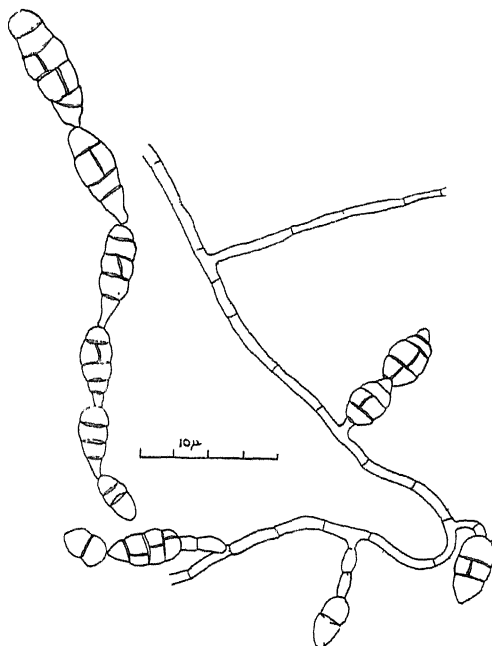


Fig. 2. Showing branched hypha with spores of *Alternaria tenuis*. A chain of 6 spores is also shown to indicate the arrangement of the spores.

A. tenuis has not been reported on diseased grains of wheat from India. Galloway (6) isolated an *Alternaria* of *tenuis* group from Indian soil, McRae (13) reported a species of *Alternaria* along with *Helminthosporium*, *Acrothecium* and *Rhizoctonia* in the foot-rot disease of wheat at Dharwar, C. P., but the exact rôle of different organisms was not established. Dastur (3) has described a black point disease of wheat from the Central Provinces but the fungi isolated were mainly two species of *Helminthosporium*, *Acrothecium* sp., *Fusarium* sp., *Phoma* sp., and *Ophiobolus* sp. It may, however, be pointed out that certain workers outside India have recorded mouldiness or blackening of wheat seeds. Evans (4) who first described the 'black point' disease of wheat from the upper Mississippi valley in 1921 reported that it

was due to a *Helminthosporium* resembling *H. sativum*. He was supported by Henry (9) who, however, found that two other species of the same genus as well as *Stemphylium* could produce similar symptoms by artificial inoculations. Grintescu (8) reported *Cladosporium graminis*, *Alternaria tenuis*, and *Fusarium avenaceum* from Rumania but inoculation results were not successful. In Great Poland and Silesia etc. Garbowski (7) obtained *Cladosporium herbarum*, *Alternaria* and *Epicoccum neglectum*. The records from Italy include *Alternaria tenuis* by Sibilia *et al.* (18), *Alternaria* and *Cladosporium* by Peyronel (15) and *A. peglionii* by Curzi (3). *Alternaria tenuis* alone or in association with *A. peglionii* have been reported by Richter (16) and Bockmann (1) respectively from Germany. Both these fungi have also been observed by Rosella (17) in Morocco. Though Ziling (19) had observed *A. tenuis* for many years in Siberia but it became serious in 1932 possibly because of very wet conditions caused by unusual rains. He also pointed out the difference between the grains infected with *Alternaria* and *Helminthosporium*. Machacek and Greaney (12) reported *Alternaria tenuis*, *A. peglionii*, *Helminthosporium sativum* and *H. teres* from Canada. According to them the apparent symptoms caused by *Helminthosporium* type were indistinguishable from *Alternaria* type. The infected seeds of the two series showed differences in their germination and yield of the crops etc. Fomin and Nemlienko (5) reported a number of fungi including *Alternaria* from Ukraine. The role of individual fungus was, however, not studied. It is curious that, in spite of numerous isolations of *Alternaria* from blackened wheat in Algeria, Laumont and Murat (11) concluded that it was not the direct cause of the disease. Pasinetti (14) reported the disease from Argentine but concluded that it was a physiological trouble.

The above account clearly reveals that in spite of the records of *Alternaria tenuis* on blackened wheat seeds there is no unanimity about the role of this fungus in damaging the grains. The author, however, found that the disease was caused by *A. tenuis* because it was recovered from more than 90% isolations and the symptoms could be produced artificially by this fungus in complete absence of any other. It appears that the *Alternaria* reported by Galloway (*l.c.*) from Indian soil does not cause much damage to the normal grain but when it is moistened by excessive rain this soil saprophyte may act as a facultative parasite and cause blackening of the grains. Garbowski (*l.c.*) and Ziling (*l.c.*) have also observed that excessive rain increased the incidence of the disease. Possibly this may also be associated with the weakened vitality of the wet grain—a fact which has been reported by Peyronel (*l.c.*) who stated that “*Alternaria*

and *Cladosporium* can invade the stigma and stamens specially after fertilization as well as glumes when they were withering" *Alternaria* is particularly adapted to the invasion of weakened organs and is commonly found in wheat grains." There is no unanimity about the damage caused by this disease. It has been reported that it merely reduced the market value on account of discoloration and had no effect on germination, growth and subsequent yield of the crop but some records indicate decreased germination and even stunting of the plants reared from diseased seeds. A full account will be published later.

ACKNOWLEDGMENT.

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OBSERVATIONS ON THE AERIAL MODE OF RESPIRATION AND
CORRELATED STRUCTURAL MODIFICATIONS OF THE
RESPIRATORY ORGANS IN CERTAIN
LOACHES (COBITIDINAE).

BY

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ABSTRACT

(1) The loaches stand at the top of the series of structural modifications for aerial respiration, affecting the alimentary canal in fishes.

(2) These modifications have resulted in the straightening of the alimentary canal, with the ultimate fusion of the stomach-diverticulum with the duodenal portion of the intestine.

(3) The stomach is not altogether absent in these loaches—it is very much abbreviated and vestigial.

INTRODUCTION

A very large number of fishes, especially amongst those inhabiting the fresh waters of tropical countries, have been known to make use of atmospheric air for respiratory purposes. The reason for this method of supplementing normal respiratory activities, has already been set down by Bridge (C. N. H. Vol. 7), Das (1927), and Carter (1931), as being due to the low Oxygen-tension of the water, forcing the animals to rise to the surface periodically and try to utilise the surface layer of water which is richer in Oxygen than the deeper layers. This impetus and movement must have led to the gulping in of small quantities of air, directly from the atmosphere. This has probably been the beginning of the series of modifications for aerial respiration in Fishes.

MODE OF RESPIRATION AND CORRELATED MODIFICATIONS IN THE
RESPIRATORY ORGANS

In the beginning the air swallowed by the fishes must have been retained only in the mouth, and for a short time, before it was let out. As examples of this condition we have the larvae of certain fishes, viz., Ophicephalidae (Das. 1927), and the adults of *Electrophorus electricus* (Carter. 1935). This latter fish possesses a very richly vascularised buccal region functioning as the accessory respiratory organ. Gradually the bubble of air must have travelled farther and farther back. In the adult Ophicephalidae (Das. 1927) two suprapharyngeal sacs have been developed near the anterior branchial region and these serve as the 'Lungs'. A similar condition is also noticed in *Amphipnous* (Das. 1927). In *Anabas* and *Clarias* such vascular lamellae or folds are present in the gill-bearing region (Das. 1927). In *Saccobranchus* the accessory respiratory structure is found in the posterior region of the branchial chamber, in the form of an elongated air-chamber. A very interesting case of the branchial chamber retaining air and serving as an accessory respiratory organ has also been described by Das (1934). This migration of the 'lung' has gone one step further back in *Ancistrus anisitsi* and *Plecostomus plecostomus* where the anterior part of the stomach has been reserved and adapted for respiratory purposes (Carter and Beadle 1931, and Carter 1935). In these forms the vitiated air is said to be forced back to the pharynx and then expelled through the mouth.

CONDITION OF THE RESPIRATORY ORGANS IN COBITIDINAE

Amongst the *Cobitidinae* (Loaches), wherever this mode of supplementing the Oxygen-supply is resorted to, we find that the greater portion of the alimentary canal has been affected. Curiously enough, the alimentary canal has been converted into a straight tube running from the mouth to the anus. The air is taken in through the mouth, and after being retained in the intestine for some time, is expelled through the anus. We have, here, the culmination of the series of changes affecting the alimentary canal, correlated with and consequent upon the constant habit of taking in air for respiratory purposes, by these fishes.

The straightening of the alimentary canal and the consequent disappearance of a stomach-like diverticulum in its course, has led Lupu (1910 et seq.) to the conclusion that these loaches have no stomach. This author divides the alimentary canal into two regions—1) an anterior digestive portion, and 2 a posterior respiratory region. During the course of my preliminary observations, I found that in *Lepidocephalichthys thermalis* (*Cobitis thermalis*)—a

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loach from South India—the stomach is not entirely absent, but only very much abbreviated. While working in the University College, London, I made sections of the alimentary canal of *Cobitis fossilis* and *C. taenia*, and there too I found similar conditions. A comparative study of the other Cobitids was then undertaken by me and the results are given below. My best thanks are due to Dr. S. L. Hora of the Indian Museum, Calcutta, for specimens of *Acanthopthalmus pangia* and *Somileptes gongota*; to the authorities of the American Museum of Natural History, for specimens of *Leptobotia*, *Lefua*, and *Misgurnus anyullicaudatus* from N. China: and to Dr. B. K. Das, Professor of Zoology, Osmania University, Hyderabad (Deccan) for valuable suggestions.

Of the loaches so far examined by me, *Botia*, *Leptobotia* and *Lefua* do not show, in their preserved state, any adaptations for aerial respiration. The alimentary canal does not show any deviation from the normal. The others show yeculiarities which fit into the scheme of explanation attempted and herein set forth by me.

Description of the Alimentary Tracts of the Cobitids.

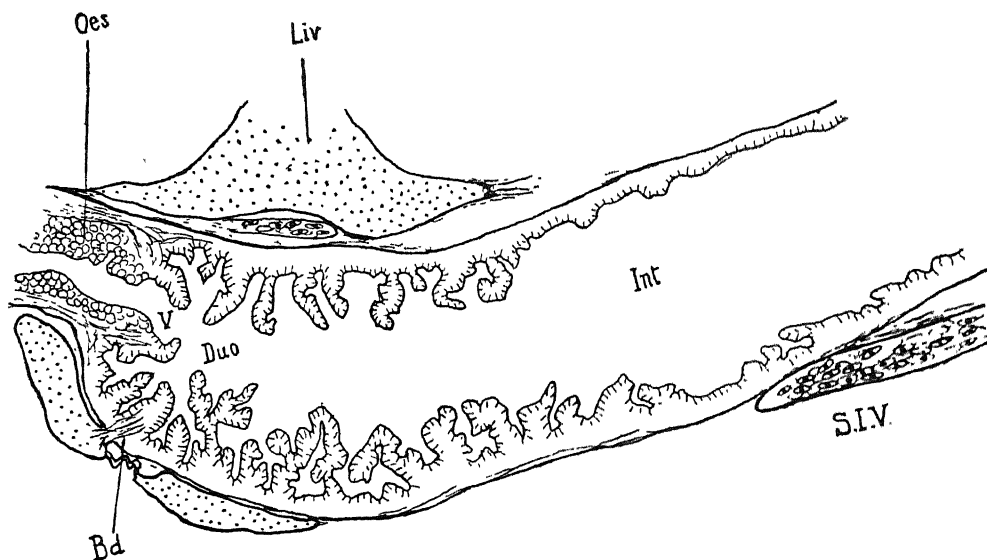


Fig. 1. Longitudinal section of the Alimentary canal of *Lepidocephalichthys thermalis*
 Bd.—place of entry of Bile duct. Duo.—Duodenum. Int.—Intestine. Liv.—Liver. Oes.—
 Oesophagus. S. I. V.—Sub-Intestinal vein. V.—“Valve.”

Lepidocephalichthys thermalis:—Figure 1 is a camera lucida tracing of a longitudinal section of the alimentary canal of this fish. An anterior digestive tract (Duo) with intricate foldings of the mucosa and a posterior respiratory region (Int) with the wall thinned out, can be observed—as described by Lupu for *Cobitis*. Dr. Das (1935) has kindly brought to my notice that he has observed a similar condition in another South Indian loach—*Lepidocephalus guntea*. But the most important structure is a valve-like projection (V) of the alimentary canal in its anterior portion. This seems to have missed the observation of the earlier workers. One can now

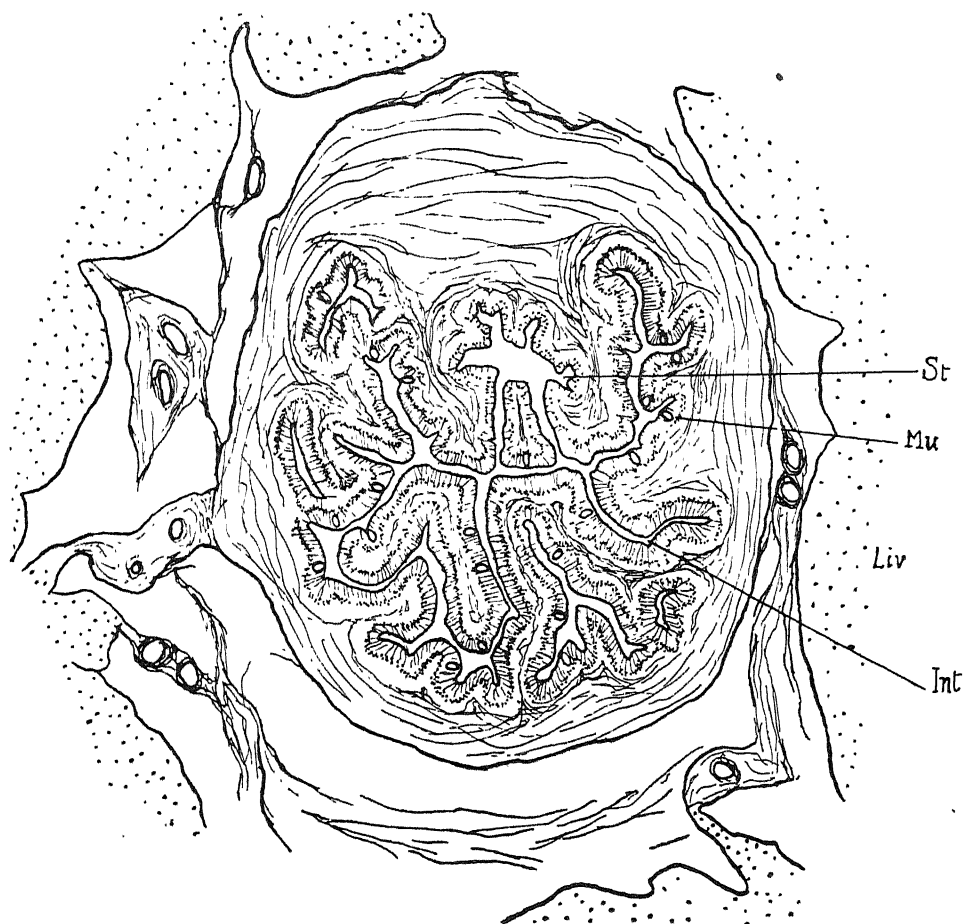


Fig. 2 Transverse section of the Alimentary canal of *Lepidocephalichthys thermalis*.
Int.—Intestine. Liv.—Liver. Mu.—Mucus cells in the Intestinal epithelium. St.—Stomach.

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make out three regions in the alimentary canal:—1) the Oesophageal region (Oes) with large vacuolated cells full of mucus; 2) the region (V) included in the valve-like extension of the Oesophageal region, showing a simple epithelial lining; and 3) the region (Duo) beyond the 'valve', with intricate foldings of its mucosa. The place of entry of the bile ducts can also be seen in this figure. This is situated just beyond the 'Valve.' In transverse sections passing at the level of the 'valve', the differences in the nature of the epithelia in the regions within and outside the 'valve' can be made out (ref. Fig. 2). It will be seen that the lining of the region included inside the 'valve' is made up of cubical cells without any trace of mucus cells, while on the outer face of the 'valve' and beyond, the epithelium is made up of columnar cells with many mucus cells included in between.

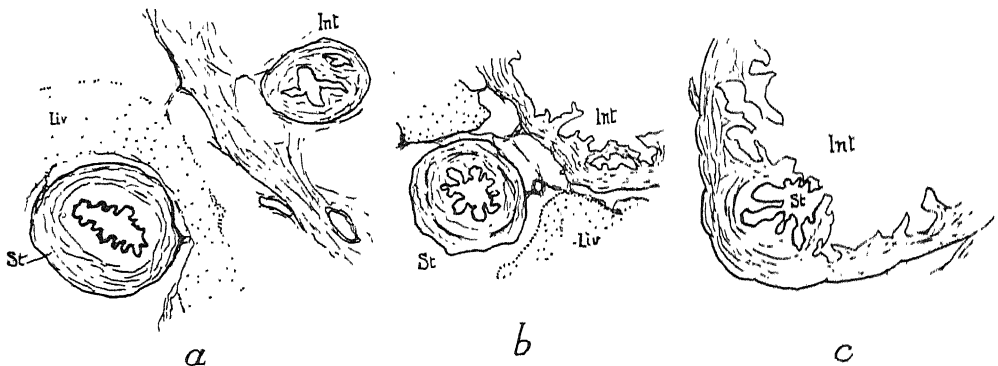


Fig. 3. Transverse sections at different levels of the alimentary canal of *Somileptes gongota*. Int.—Intestine. Liv.—Liver. St.—Stomach.

Somileptes gongota:—Figure 3 represents drawings of transverse sections at different levels, of the anterior part of the alimentary canal. At A, the alimentary canal is seen to be cut in two places. One of these cavities (St.) is continuous with the oesophageal region in front, while the other (Int) is just making its appearance. Enough can be made out from the histological nature of the sections to state that the epithelia lining these two cavities are very different indeed. In B, the two cavities have come nearer and the second cavity (Int) has become so enormously big that only a part of it could be shown in the drawing. In C, the smaller cavity (St) is seen merging into the bigger cavity (Int) which is continuous with the intestine. It will thus be seen that what appeared as a valve-like fold in *Lepidocephalichthys*, here appears as a regular diverticulum of the alimentary canal, though not big

enough to be visible on a gross inspection. The total length of this stomach diverticulum in this fish is about 1.1 mm in a specimen of average size.

In *Acanthophthalmus*, I could not find any trace of a stomach-like diverticulum, nor of any valve-like fold. The anterior part of the alimentary canal was, however, very much dilated. In *Misgurnus anguillicaudatus*, the conditions were very much like those in *Cobitis*, including the presence of a bend in the posterior portion of the alimentary canal. This bend was not to be seen in any of the other specimens described above.

DISCUSSION.

In fishes which are mainly carnivorous, it is very well known that the alimentary canal is short and simple, bent like the letter N. If during the course of evolution, the limbs of the N-like bend were to come together and fuse, we would, it is very interesting to note, arrive at a condition resembling that noticed in the Loaches mentioned above. Similar fusion and consequent straightening of the alimentary canal have already been noticed in *Campostomus* (Rogick. 1931) and in *Symbranchus* (Taylor. 1913). In these cases the authors have taken the point of entry of the bile duct to mark out the beginning of the intestine. Similarly in the Cobitidine, the region of the alimentary canal situated beyond the valve-like inpushing of the oesophageal

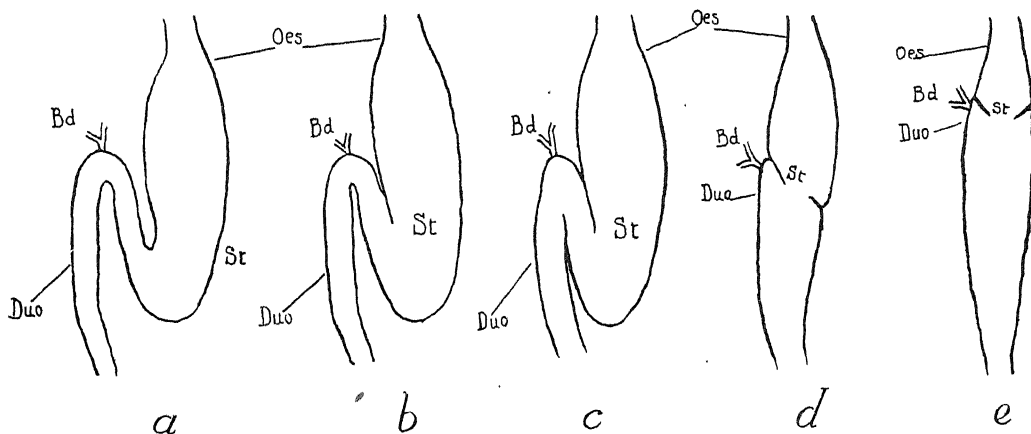


Fig. 4. Schematic representation to show how the straight alimentary canal of the *Cobitidinae* has come into being. A—represents the typical condition in fish; B—an intermediary stage; C.—another interim stage typified by what is seen in *Somileptes gongota.*; E—a stage as seen in *Lepidocephalichthys thermalis*. Bd.—Place of entry of bile duct, Duo.—Duodenum. Oes.—Oesophagus. St.—Stomach.

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region, would be the intestine proper, while the region included within this 'valve' and possessing an epithelium made up of cubical cells, and without any trace of mucus cells, would be the *very much abbreviated stomach*. Evidently Lupu and other continental workers seem to have missed this interesting structure, while making their observations on the European loaches. The gradual modifications and passage from one condition of the alimentary canal into another, and possible way as to how this straightening of the alimentary canal could have taken place may be expressed by a series of diagrammatic sketches as shown in Fig. 4. At one end of the series (Fig. 4a) we have the typical condition as seen in carnivorous fishes, while at the other end we have (Fig. 4e) a condition as seen in *Lepidocephalichthys*. *Somileptes* comes in as a very handy intermediary stage (Fig. 4c).

The interesting series of modifications as evinced by these Cobitids have naturally evolved to facilitate an easy passage for the respiratory bubble of air, which in these forms seems to have travelled without any obstruction, so far down the length of the alimentary canal as not to allow of any 'regurgitation' but simply to be finally forced out of the anus. These modifications have thus helped to make a perfect mode of intestinal respiration.

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ON SOME ECOLOGICAL FEATURES OF THE VEGETATION AT Mt. ABU

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ABSTRACT

Mt. Abu is a part of a very ancient chain of mountains in India. Its vegetation however has remained mostly unexplored. The paper, therefore, makes an attempt at depicting it on a small scale by giving an account of the principal plant formations found at various levels and of the factors controlling them. The vegetation is of the monsoon deciduous type but abounds in many xerophytic species governed largely by the edaphic and climatic factors. The principal formation on the table-land is *Carissa-Euphorbia* association spread over a large area. The vegetation at the foot of the mountain is a woodland savannah on the eastern side and a scrub on the western side. The vegetation in the valleys conforms to the usual monsoon deciduous type found in the valleys in Peninsular India, western Himalayas etc. In particular, it shows a greater resemblance with the vegetation found in the forests on the outer borders of western Himalayas up to about 1,500 feet elevation.

INTRODUCTION

Mount Abu is a southerly outlier of the Arawallis, an ancient chain of mountains that came into existence during the great orogenic upheaval towards the close of Dharwar era of the Archean period in Indian geology. It was a playground of glaciers during the Permo-carboniferous period and since then has been subjected to severe weathering, as a result of which it stands to-day a much denuded chain of rocks forming huge rounded boulders. Mt. Abu proper, however, is separated from the the main range of the Arawallis by the valley of the river Banas to the East, nearly 15 miles, broad, and includes in the cluster of hills the highest peak of the Arawallis, *Gurushikhar*, the 'Pinnacle of Saints' lying at the junction of the deserts of Rajaputana, Indus valley, the plateaux of Marwar and Malva, and the plains of Northern Gujarat. It is no wonder then that the vegetation of such a place should be varied and interesting. But unfortunately with the exception of a few cursory references to it in Hooker and Thomson (1855), Hooker (1906), King (1897), Champion (1936), McCann (1942), a list of plants collected in the months October to December by Miss Macadam (1890), published near ly

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years back, and a brief account of the plants recently collected by Sutaria (1941), the vegetation of this ancient place has remained mostly unexplored. The object of the present paper therefore is to give an account of some ecological features of the vegetation of this place and the factors that control it.

DESCRIPTION

A. *Ecological Factors.*

Topography.—Mt. Abu, Lat. 24, 35 37 N., Longt. 32, 47 16 E., is about 120 miles away from Ahmedabad. It arises as a singular cluster of hills from the base of a jungle nearly 20 miles in length. Its average height above the sea-level is little more than 4,000 feet, the highest point, the *Gurushikar*, being 5,653 feet above the sea-level (Pl. I, Fig. 1) The hill station of Mt. Abu is situated at a lower level than this on a table-land 13 × 3 miles in extent, and is much rugged in outline on account of the precipitious walls of the granitic rocks encircling it. These are mostly primary, highly crystalline and schistose : they consist mainly of syenite, and when weather give rise to large honey-comb-like cavities seen everywhere at Mt. Abu (Pl. I, Fig. 3). At places they hold small sheets of water forming lakes surrounded on all sides by rocky peaks (Pl. I, Fig. 4). The dip of the strata in general is to the East. The eastern boundry of the hill station is formed by a long escarpment of rocks which breaks into spurs on the southern and eastern sides to form valleys covered with jungle.

Climate.—The climate is temperate, dry, and highly favourable for a steady growth of certain types of vegetation. The rainy season is short, lasting from about the middle of June to the end of September. The remaining period of the year is rainless and dry (see Tables I and II).

Table 1—showing the data regarding the mean maximum and minimum temperature in different months of the year at Mt. Abu observatory at 3,955 feet elevation based on averages of several years (vide *Ind. Met. Mem.*, XVII, 1904 and 1917).

	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
Mean maximum	66·6	68·8	77·7	85·7	88·2	83·3	74·6	72·0	75·3	78·8	73·5	68·6
Mean minimum	51·2	61·5	61·5	69·1	71·1	68·1	65·7	64·2	64·6	64·3	57·9	52·9

Temperature.—The annual mean maximum temperature varies between 66.6° F and 88.2° F, the average for the 12 months being 76.1° F. The mean minimum temperature varies between 51.2° F and 71.1° F, the average mean for 12 months being 62.0° F. The absolute minimum recorded previous to the year 1903 varies between 32.8 and 58.9, the lowest figure having been recorded in the months of January and February. Differ. Absolute maximum and minimum of the year is 68.2. The diurnal variations in the temperature are within 10 degrees, the average for 12 months being 14.1 (See Table I).

The Rainfall and Water-table.—The average rainfall per year is 62.49 inches distributed over 54.6 rainy days (See Table II). Most of it is due to South-West monsoons from the middle of June to the middle of September. There are no precipitations due to return monsoons. Fog and hail storms do occur but not frequently.

Table II—showing the amount of rainfall and the number of rainy days in different months of the year at Mt. Abu based on averages of several years (see *Ind. Met. Mem.*, 1904).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rain-fall in inches	0.27	0.31	0.15	0.08	0.97	5.59	22.05	21.51	9.58	1.46	0.28	0.24
No. of rainy days	0.7	0.5	0.5	0.3	1.3	6.7	17.6	17.2	8.0	0.5	0.4	0.5

Total rainfall for the year 62.49 inches.

Total number of rainy days* 54.6.

The water-table is not very deep. Good supply of water can be had at about 20-40 feet below the level of the soil. The sub-soil water currents are not very powerful, as the capacity of the rocks to hold water is not so great as that of the traps in the Deccan. The greater part of the monsoon precipitation, therefore, is washed down into the valleys.

Light.—The general slope of the rocks being to the East, the easterly sides and southerly spurs are well lit. But in the ravines on the south-westerly side of the table-land (on which is situated the hill station of Mt Abu) are not very well illuminated, and support nothing but a poor undergrowth of annuals and grass.

(* A day on which 0.1 inch of rain falls is considered a rainy day.)

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Wind and Humidity.—The only winds of ecological significance are the water-laden South West monsoons moving with a moderate velocity of about 10-12 miles per hour over the place. During the other parts of the year the air is not so humid. The relative humidity attains its maximum value at 8-0 A.M. in the months of July and August, 95.5 and 95.8 respectively, the lowest, 28.5 being attained in the month of April at 8-0 A.M., and 22.5 at 4 P.M. in the same month (See Table III below).

Table III—showing the average percentage of the relative humidity at Mt. Abu (See *Ind. Met., Mem.*, 1904, 1917).

	Jan.	Feb.	Mart	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
8 A.M.	44.4	41.8	35.4	28.05	40.3	72.9	95.5	95.8	79.6	44.3	41.8	43.7
4 P.M.	37.2	29.7	25.0	22.5	30.6	54.9	80.4	85.3	72.6	38.9	33.2	36.6
	Yearly average 8 A.M. 53.3.											
	4 P.M. 45.6.											

Soil and soil-cover.—The soil is derived from the disintegration of the gneisses and schists but as the particles are quickly removed by the denuding agencies at work here, it is rather thin. It is poor in plant nutrients and its capacity to hold water is very limited. In the valleys however the particles accumulate in large quantities and get mixed with the dry foliage and other organic debris and form belts of vegetation on sandy loam alternating with barren tracts of denuded rocks. The dead foliage adds much to the fertility of the soil and plays an important part in maintaining certain species whose seedlings need shade, e.g. *Ailanthus excelsa* or *Eugenia Jambolana*.

Biotic factors.—No grass-lands of any great importance occur on the table-land and there is no special attraction for the herdsmen to graze the cattle or sheep. The wild animals likely to disturb the vegetation are also not many. The insects, birds and fungi which also play a minor role in controlling the vegetation of a place are few e.g. *Locusta migratoria*, *Schistocerca gregaria*, passerine birds, ascomycetous fungi like *Glomerella* and rusts like *Uromyces Hobsoni* and *Puccinia Thwaitesii* growing on two species of *Jasminum*, *malabaricum* and *grandiflorum*.

Man has, however, played havoc by annihilating some parts of the forest on the table-land by cutting down the wood and bamboos to extend the limits of the habitable area or by his attempts to bring the forest land under cultivation. This has probably changed the equilibrium between the forest cover, temperature and rainfall with the result that the vegetation on the southerly and south-eastern sides of the hill station is fast dying out. The wholesome influence of man also must not be denied. He has, for example, added many new species to the flora of the mountain, some of which are well domiciled here, e.g. *Grevillea robusta*, *Pinus longifolia*, *Eucalyptus globulus* and many garden plants. Out of these *Solanum jasminoides*, species of *Ageratum* and *Zinnia* have escaped and run wild. A detailed quantitative analysis of the plants growing here shows that the following are the principal families: Gramineae, Leguminosae, Compositae, Cyperaceae, Scrophulariaceae, Labiatae, Boraginaceae, Malvaceae Euphorbiaceae, Convolvulaceae and Acanthaceae. Of these the last two families are of equal importance in point of species.

VEGETATIONAL TYPES

Without entering into the theoretical discussion as to the terms to be used to describe the types of Indian vegetation, the vegetation of Mt. Abu may be said to consist of the following formations, using the term formation in the sense in which it has been used by Warming (1909, p. 140):—

1. Formations at the foot of the mountain
 - (a) on the Eastern side,
 - (b) on the Western side,
 2. Formations on slopes upto about 3,000 feet elevation;
 3. Formations on the table-land above 3,000 feet elevation.
1. (a) *Formations, at the foot of the mountain on the Eastern side.*

The vegetation on this side is a wood-land savannah consisting of *Butea frondosa*, *Odina Wodier*, *Sterculia urens*, *Diospyros melanoxylon*, *Sterculia colorata*, *Saccharum Munja*, *S. spontaneum* and *Heteropogon contortus*. As one climbs higher up to about 2,000 feet elevation one finds that large tracts of slopes are occupied by *Boswellia serrata*, *Holarrhena antidysenterica*, *Melhania futteyporensis*, *Grewia tiliaefolia*, *Garuga pinnata*, *Cedrela Toona*, *Ailanthus excelsa* and bamboos. Above 2,500 feet elevation the aspect of the slopes is dominated by *Boswellia serrata*, *Holarrhena antidysenterica*, *Wrightia tinctoria*, *Aegle Marmelos*, and *Nyctanthes Arbor-tristis*. As one

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climbs still higher up, these species gradually thin out and give way to a xerophytic community. The constituent elements of this community are *Flacourtia sapida*, *Carissa Carandas*, *Capparis sepiaria*, *Acacia Catechu*, *Balanites Roxburghii*, *Celastrus paniculata*, *Zizyphus rugosa* freely mixed with huge clumps of *Euphorbia neriifolia* (Pl. I, Fig. 3). Thus, there is a scrub community on both the sides of the wood-land savannah at the foot of the mountain on the eastern side.

1. (b) *Formations at the foot of the mountain on the western side.*

These consist of a very narrow belt of wood-land savannah more or less of the same kind described above, but they suddenly open out into a scrub community of *Acaia arabica*, *Capparis aphylla*, *Salvadora persica*, *Prosopis spicigera*, *Bergia odorata*, and thin out at no great a distance into a tract of barren sand.

2. *Formations on the slopes up to about 3,000 feet above sea-level on the northern and north-eastern sides.*

The rocky and exposed parts on these sides have *Eriophorum comosum*, a sedge, *Gymnosporia montana*, *Hamiltonia suaveolens*, *Clerodendron Phlomidis*, *Carissa Carandas*, *Celastrus paniculata*; and in the valleys grow *Eugenia Jambolana*, *Cedrela Toona*, *Bauhinia purpurea*, *Mollugo hirta*, *Wagatea spicata*, *Sterculia urens*, *Helicteres isora* and *Mangifera indica* (planted).

3. *Formations on the table-land above 3,500 feet elevation.*

There is a remarkable change in the climate and vegetation above 3,500 feet elevation. The former becomes considerably cooler, and tall trees of *Ailanthus excelsa*, *Grevillea robusta*, *Cedrela Toona* and *Eucalypts globulus* begin to appear everywhere. On huge boulders nothing but *Euphorbia neriifolia* seems to grow e.g. on Toad Rock (Pl. I, Fig. 3); and in the pockets of rocks where some soil has been collected *Phoenix sylvestris*, *Anogeissus pendula*, *Mallotus philippinensis* and *Carissa Carandas* raise their heads here and there. On hard unpromising rocks grow *Vogelia indica*, *Plumbago zeylanica*, *Barleria cristata*, *Ficus religiosa*, *Woodfordia fruticosa*, *Morus indica*, *Pistacea integerrima*, *Cryptolespis buchanani*, *Marsdenia volubilis*, grasses like *Andropogon contortus*, *Andropogon annulatus*, and *Cymbopogon Martini*. In extreme xerophytic situations at altitudes higher than this, nothing but stray belts of *Euphorbia ligularia* are seen; whereas the highest peak of the mountain, Gurushikhar, is practically devoid of vegetation but for a few shrubs, thalloid plants and

lichens (Pl. I, Fig. 1), probably due to the absence of soil and active denudation of rocks at such great heights. The greater part of the tableland however is occupied by a scrub community consisting of *Carissa Carandas*, *Aegle Marmelos*, *Anogeissus pendula*, *Mollugo hirta*, *Cordia Rothii*, *Flacourtia Ramontechi*, *Phyllanthus Emblica*, *Nyctanthes Arbor-tristis*, *Phoenix sylvestris* mixed with lianes like *Celastrus paniculata*, *Hiptage madablota*, *Cæsalpinia sepiaria*, species of *Convolvulus*, *Capparis trinervis*, *Mærua arenaria*, *Vitis trifolia* and clumps of *Euphorbia neriifolia* (Pl. I, Figs. 1 and 3). This community probably represents an edaphic climax and owes its origin to topographical succession.

Valleys at the higher altitudes have deciduous species such as *Sterculia urens*, *Dalbergia Sisoo*, *Albizzia Lebbek*, *Triumfetta pilosa*, *Mangifera indica* (cultivated but run wild), *Holoptelea integrifolia*, *Adalia retusa*, *Eugenia Jambolana*, *Bassia latifolia* and bamboos (Pl. I, Fig. 2). These are mixed up with the thickets of *Strobilanthes*, *Ixora parviflora*, *Mallotus philippinensis*, *Jasminum malabaricum* and *Pueraria tuberosa*. The undergrowth is mostly of the herbaceous plants like *Girardinia heterophylla*, *Geranium ocellatum*, *Pogostemon parviflorum*, *Physalis minima*, *Capsella Bursa-pastoris*, *Cardamine hirsuta*, *Artemisia vulgaris*, species of ferns like *Athyrium*, *Nephrodium cicutarium* and *Cheilanthes farinosa*. In damp places one finds fibrous species of grass, *Pennisetum Alopecuroides*. But such valleys having rich vegetation are not many at Mt. Abu. The one shown in Pl. I, Fig. 2 is the valley one has to descend to reach 'Gomukh' on the South-east side of the hill station. In winter many of the plants shed their leaves and a typical monsoon deciduous forest is noticeable (Pl. I, Fig. 5).

The xerophytic community at Mt. Abu often passes into aquatic formations in ponds and lakes (Pl. I, Fig. 4). One often notices a complete sector of a xeric sere passing into an hydrarch sere. The xeric sere starts with crustaceous lichens, followed by mosses, liverworts e.g. *Riccia discolor* (*himalayensis*), *Plagiochasma appendiculatum*, ferns like *Adiantum lunulatum* and the peculiar *Asplenium hymenophylloides* and the flowering petrophytes like *Arenaria* sp., *Linaria ramosissima*, orchids like *Aerides crispum*, *Ficus religiosa*, *Vogelia indica*, and *Carissa Carandas*. The aquatic formations consist of *Nymphaea Lotus*, *Lymnophyton obtusifolium*, *Potamogeton crispus*, *Polygonum serrulatum*, *Lemna polyrrhiza*, *Carex mysorus*, *Ceratophyllum demersum*, *Najas minor*, *Azolla pinnata*, *Marsilea quadrifolia* etc. But what one misses here is the wet meadow stage so very conspicuous under similar situations in the trap hills of Deccan. Perhaps this is due to the fact that

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there is very little or no soil on the margins of pools at Mt. Abu, and that the rocks are poorer in plant nutrients. This inference also gains some further support from the fact that in the case of those lakes which have been artificially constructed one does notice a small belt of reed-swamp community on their margins due to gradual accumulation of soil, e.g. on the municipal lake, Bandere-mere. On the banks of this lake due to the construction of a thick wall; a small amount of mud is now collected in which grow reeds, *Salix tetrasperma*, *Ranunculus sceleratus* *Potentilla supina* and *Carex mysorus*. In the neighbourhood grow *Rosa Lyellii*, the indigenous rose of Mt. Abu, *Berberis asiatica* and *Phoenix sylvestris*. The last species also occurs on the islands in the Nakhi Lake and on the hills even above 4,500 feet elevation e. g. on the hill opposite Achalgiri (Pl. I, Fig 4). This is really a strange feature of the flora of Mt. Abu, reminding one of similar scenes in the trap hills around Bombay abounding in palmyra and other palms. Equally striking are the belts of *Euphorbia ligularia* at great heights in places precariously high and almost inaccessible.

The vertical section of the whole vegetation at Mt. Abu, thus, seen from top to the foot of the mountain will be like the following:—

Height above the sea-level	Vegetational types.
Top .....5,653 feet	Little or no vegetation except a few thalloid forms, and shrubs.
.....5,000 feet	Stray belts of <i>Euphorbia ligularia</i> . Clumps of <i>Euphorbia neriifolia</i> .
.....4,500 feet	<i>Capparis trinervis</i> and <i>Carissa Carandas</i> .
.....4,000 feet.....	Xerophytic formations on the rocks and aquatic formations in ponds and lakes.
.....2,500 to 2,000 feet.....	A formation of <i>Boswellia</i> , <i>Dalbergia</i> , <i>Holarrhena</i> , bamboo, <i>Bauhinia</i> , <i>Odina</i> and <i>Eriophorum</i> on slopes and in the valleys.
.....1,500 feet.....	Athorn savannah of <i>Acacia</i> , <i>Capparis</i> , <i>Zizyphus</i> and allied forms.
.....1,200 feet.....	A wood-land savannah of <i>Butea</i> , <i>Odina</i> and <i>Sterculias</i> mixed with grasses.

.....1,100 to	A low scrub mainly <i>Prosopis spici-</i>
600 feet.....	<i>gera</i> , <i>Salvadora persica</i> and <i>Salvadora</i>
	<i>oleoides</i> .
Foot .....500 feet.....	Poor grass-lands on the Western,
	North-Western and Northern sides.
	Grass-lands with perennial Grami-
	neae e. g. <i>Saccharum Munja</i> on sandy
	loam on the eastern and southern
	sides.

DISCUSSION

The vegetation at Mt. Abu with its varied geographical features exhibits a variety of ecological conditions. It is well known, that the plant life in general and the distribution of plants in particular, in India, is dependent on the monsoon precipitations; and under natural conditions tends to produce what are known as the monsoon deciduous forests [Hooker (1906), Calder (1937), Dudgeon and Kenoyer (1925), and Champion (1936, 1939)]. There are three kinds of monsoon deciduous forests in India:

- (a) the upper monsoon forests found on the outer slopes and in the valleys of rivers in the Himalayas from 2,000-5,000 feet elevation;
- (b) *Shorea robusta* forests forming a narrow strip on the lower slopes of the Himalayas from 1,000-2,000 feet elevation and
- (c) peninsular monsoon forests quite common all over the Deccan, the Indo-Gangetic plains and the outer borders of the Himalayas up to about 1,500 feet elevation.

There is a vast difference between the climatic conditions under which the forests in (a) and (b) types grow and those under which the forests of the (c) type grow. Taking into account the dryness of the climate, and the unevenly distributed rainfall over the year and the poor nature of the soil at Mt. Abu, it is evident that its vegetation is rather like the one found in the peninsular monsoon forests. This conclusion is further confirmed by the absence of *Shorea robusta* belts in this region. But whether it is similar to that in the forests of the Deccan or to that in the Indo-Gangetic plains or to that in the forests on the outer borders of the Western Himalayas is a question not easy to decide. If one relies on the component elements in the vegetation at Mt. Abu to solve this question, the absence of *Guttiferae* and

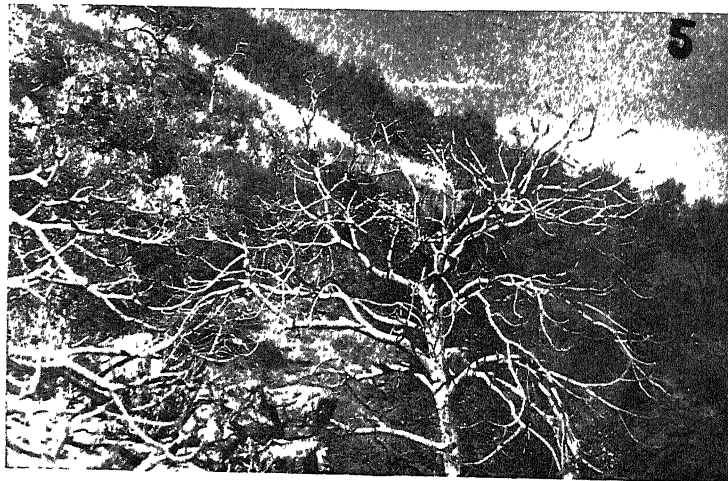
those species of Combretaceae which are so common in the peninsular monsoon forests of India, one is tempted to believe that the vegetation at Mt. Abu is not much like that in the peninsular forests of India. But such a conclusion would be hazardous in view of the fact that the Sterculiaceae, Combretaceae and many other families found at Mt. Abu are decidedly of Indo-Malayan origin. The other dominant elements in the vegetation at Mt. Abu are the Capparidaceae, Salvadoraceae and some Leguminosae which are of the Perso-Arabic origin. The presence of these elements is explicable on account of the fact that Mt. Abu lies on the border-land of Cutch, Kathiawar and the Indus valley where these elements are found in great abundance. But the real difficulty in this connection is presented by the species of Himalayan origin. The Rosaceae, Salicaceae, Berberidaceae and Ranunculaceae found at Mt. Abu are of Himalayan origin. Many of these reach their extreme southerly limit at Mt. Abu, Whether this is due to historical reasons or due to climatic conditions only, may still be left an open question. But if one takes all these elements into account and views them as a whole, one feels that there is sufficient justification for agreeing with the view about the vegetation of Mt. Abu, so ably expressed, now more than 85 years ago, by Sir J. D. Hooker and Thompson (1855.) They say: "The forest-clad slopes of the Arawali range are so dry for nine months of the year, that only those trees which are tolerant of great dryness can grow there. They may, therefore, be expected to present a vegetation similar to that of the hills of Gujarat (see Saxton and Sedgwick, 1918), or the Western or the drier Himalaya where the climate is similar. The summit of Abu, like that of Parasnath, produces some epiphytic Orchidaceae and other humid types, but their number is no doubt inconsiderable."

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In conclusion we wish to express our debt of thanks to Professor S. P. Agharkar, M.A., Ph.D., F.L.S., for suggestions and criticism of the manuscript. Our best thanks are also due to Professors B. Sahni and S. L. Ajrekar for many helpful suggestions and to Professors J. J. Asana and R. N. Sutaria for their willing help in course of this investigation.

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EXPLANATION OF PLATE

- Fig. 1. *Gurushikhar*, the 'Pinnacle of Saints,' the highest peak of the Arawallis, 5,663 feet above sea-level. Note the barren rocks at the top of the mountain and a few shrubs of *Carissa Carandas*, *Euphorbia neriifolia*, *Capparis trinervise* and such other plants at a lower altitude.
- Fig. 2. A monsoon forest in the valley on way to Gomukh, at about 3,500 feet elevation, rich in many deciduous species.
- Fig. 3. "Toad Rock" at Mt Abu. Note the honeycomb-like cavities in the rock and the clumps of *Euphorbia neriifolia* at the right.
- Fig. 4. A view of vegetation in and around the Nakhi Lake.
- Fig. 5. A typical view of the monsoon deciduous forests in winter abounding in *Sterculia urens* and other trees without leaves.

STUDIES ON THE RANJAN X-RAY MUTANT WHEATS

II. A preliminary account of the cytology of the variants

By

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ABSTRACT

Cytological examination of the eleven Ranjan mutants showed that in them the diploid number of chromosomes is 42 and haploid 21.

There has thus been no change in the number of the chromosomes. However variations in the sizes and shapes of the chromosomes were noticeable.

The obvious conclusion is that change in the number of the chromosomes has not played any part in the formation of these variants, but changes in the number or arrangement of the genes or these and the gene mutations are responsible for the production of these mutants.

During the past 15 years radiation has been shown to be highly productive of cytogenetic alterations in a variety of plants. In the previous paper of this series (Ranjan, 1940) the changes in the morphological characters brought about by treatment with X-rays have been noted. In this paper the 11 mutants thus obtained were examined cytologically to study whether any visible cytological variations existed or not in these mutants.

For the cytological studies the seeds of the 11 variants and I. P. 52 were collected from plants producing X_2 plants. These were germinated on moist filter paper in separate dishes. When the roots were about 1 cm. long, one set of the root tips were cut and fixed in Maeda's modification of Navashin's fluid and a second set in Kagawa's (1929) solution. Maeda's fixative proved satisfactory. For meiotic studies flower buds (of X_2 generation) were fixed in Maeda's solution. After fixation the roots and flower buds were washed, dehydrated in alcohol, cleared in chloroform and embedded in paraffin. Transverse sections of roots were cut at 12 to 15 μ and sections of flower buds at 10 to 12 μ and were stained in Newton's modification of iodine-gentian-violet. The most suitable time, for fixing the roots for maximum division stages, was found to be between 11 a.m.—12 noon and for flower buds between 9 a.m. and 11 a.m.

Mitosis:—The chromosomes of the mutants as well as of I. P. 52 are given in Figs. 1 to 12. These figures are of the chromosomes at polar view of metaphase and were drawn with the help of camera lucida and are reproduced at a magnification of 3,000 dia. The chromosome numbers were counted. It is observed that the somatic chromosome number in all the 11 mutants as well as in I. P. 52, is 42. But the mutants showed variations in the sizes and shapes of the chromosomes. It is assumed that this is partly due to structural variations in the chromosomes caused by X-ray though these differences might have been exaggerated by differences in orientation of the chromosomes. Differences may also arise from the fact that early metaphase chromosomes appear larger than what they do at late metaphase. Further work in this matter is in progress.

Meiosis:—The pollen mother cells were favourable for these studies. The study of early prophase stages was not emphasised. At diakinesis usually all the pollen mother cells in a field exhibited the same stage of meiosis but later occasionally both meta and anaphase or even meta and telophase figures were found together. Meiosis of X_3 of strain No. R3 (all the three-3A (Awnless), 3B (short-awned) and 3C awned) and of I. P. 52 only were studied.

In 3A, awnless, the meiosis was found to be regular for only bivalents were found. Fig. 13 shows the diplotene stage where 21 bivalents are seen with one nucleolus. Fig. 14 is the first metaphase stage showing the bivalents in polar view. They are 21 in number and are in their maximum contraction. Fig. 15 and 16 are first anaphase stages where chromosomes are moving to the poles. Fig. 17 shows the second metaphase, the chromosomes are thinner and longer than at the first metaphase. This metaphasic plate has 21 chromosomes. Some of the chromosomes have satellites. Fig. 18 is second anaphase, in which some of the chromosomes have already reached the poles while a few laggards are still at the equatorial plates.

The strain 3B (short awned), (Fig. 19, 20 and 21) also had 21 bivalents, the meiosis was regular and there was no visible difference from those of 3A (awnless).

Strain 3C (awned) are depicted in figs. 22, 23, 24. There were distinctly 21 bivalents in polar view and here also there were no differences from the other strains.

Fig. 25 is the diplotene stage of I. P. 52 showing 21 bivalents with chiasmata. Figs. 26, 27 and 28 show the first metaphase, first anaphase and second anaphase respectively. Thus in 3A, 3B, 3C and I. P. 52 only bivalents were observed.

Delaunay (1930) X-rayed 50 ears of *Triticum vulgare albidum*—an awnless common wheat, and obtained 8 variant types in addition to certain monstrous forms. Six of these were found to be due to chromosomal aberrations. One, awned was considered an undoubted case of locus mutation and another, square head was considered possibly due to gene mutations. The 8 variants all arose in the progeny from ears X-rayed at meiosis and later. But when a larger group of ears were X-rayed at an earlier stage of development no variant types were obtained.

Plotnikowa (1931) X-rayed heads of wheat during meiosis and found that the treated material had got some multinucleated cells and the chromatin was clumped along the spindle threads.

Sapegin (1935, '36) also reported numerous variants in the progeny of common wheats as a result of X-ray, of which a majority were aberrant types more or less sterile but among which some apparent mutants of practical interest were included.

Raghavan and Venkatasubban (1940) X-rayed some South Indian chillies and on cytological examination concluded that change in the number of chromosomes did not play any part in the formation of the variants, however different they are, and that one should look to a structural change rather than in number or even in the morphology of the chromosomes.

That fragmentation is the most frequent and initially important product of irradiation is commented upon by Lewitsky and Araratian (1939). A frequent product of normal or induced chromosomal fragmentation is translocation in which a section of one chromosome becomes attached to another (Thompson and Thompspon, 1937 and others).

Katamaya (1935) X-rayed flowers of *T. monococcum* and *Secale cereale* and observed fragmenation and lagging chromosomes in the pollen mother cells.

In the present investigation the mutants arose from treatment at early seedling stage. It is, therefore, possible that X-rays are most effective during the division stages, meiotic (as reported by others) and somatic.

The studies of mitosis and meiosis lead to the obvious conclusion that numerical chromosomal aberrations have not played any part in the variations observed in the mutants, but changes in the number and arrangement of gene loci or these and gene mutations are responsible for the production of the mutants.

We have great pleasure in acknowledging our indebtedness to Prof. S. Ranjan and desire to express our grateful thanks for his kindly interest and helpful suggestions during this investigation.

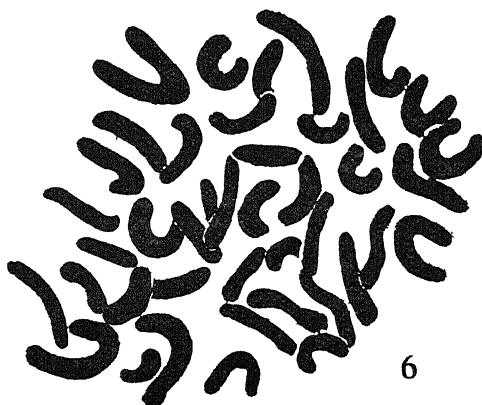
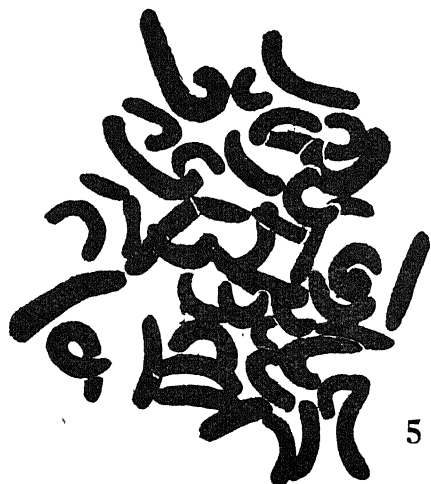
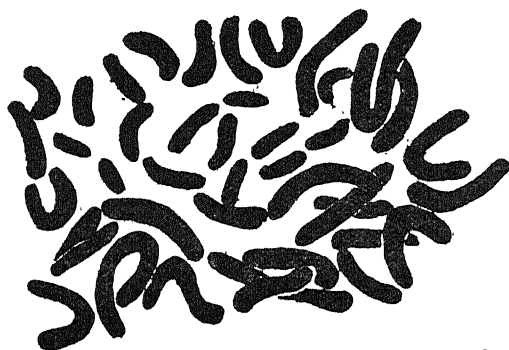
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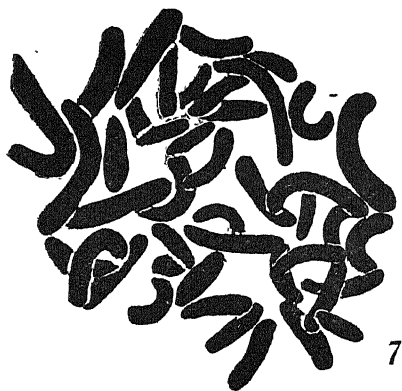
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EXPLANATION OF PLATES.

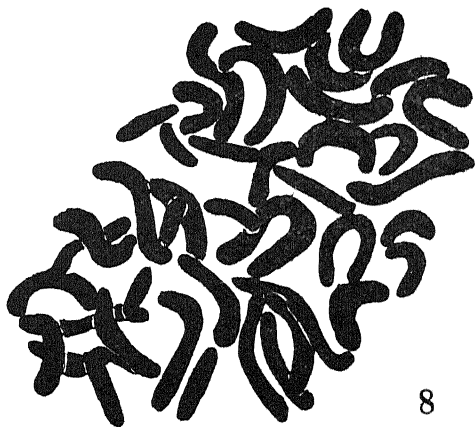
All figures were drawn with the aid of Camera lucida at table level and are reproduced at a magnification of $\times 3,000$.

- Figs. 1 to 12. Metaphase plate of mitosis in R¹, R², R³, R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, R¹⁰, R¹¹, and I. P. 52 respectively. 42 Chromosomes are seen in each.
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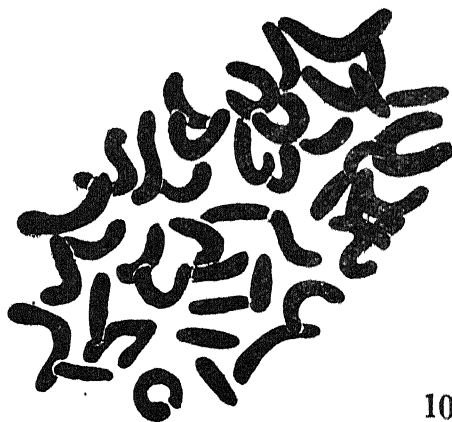
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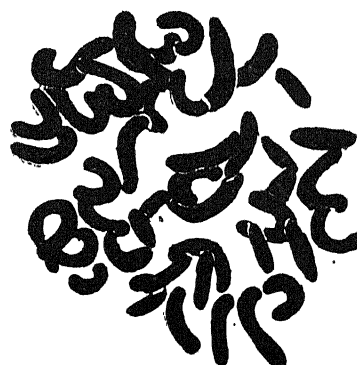
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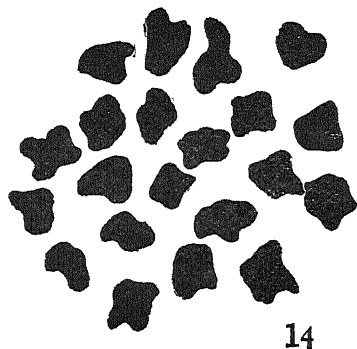
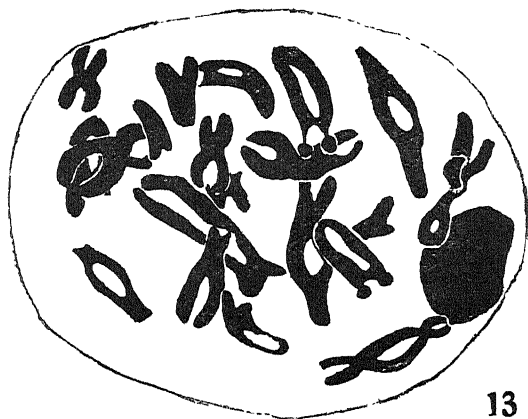
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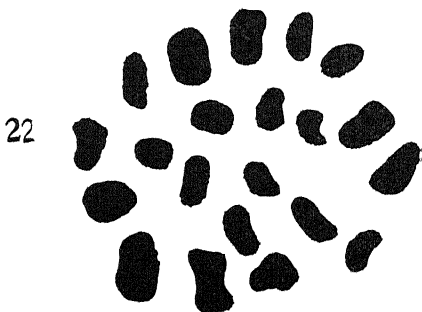
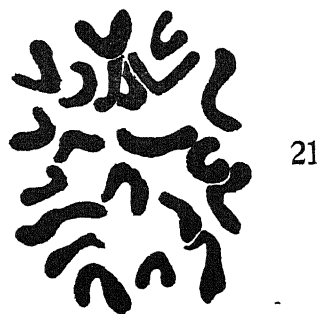


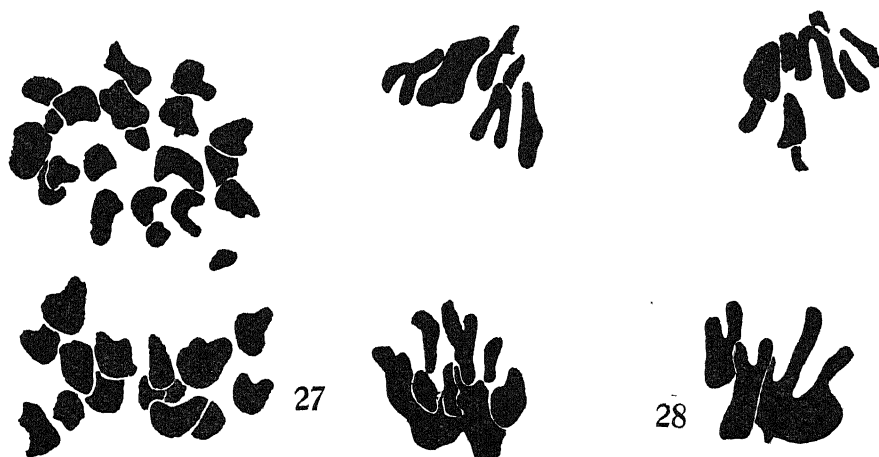
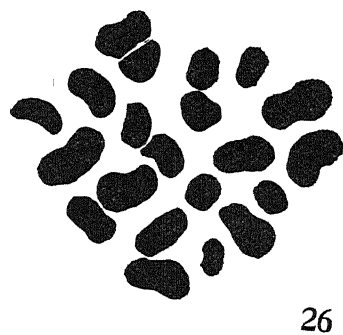
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PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES INDIA 1946

PARTS 2—4

SECTION B

VOLUME 16

SECOND SYMPOSIUM ON THE AGE OF THE SALINE SERIES IN THE SALT RANGE OF THE PUNJAB

held at Udaipur on 27 and 28 December 1945 under the joint auspices
of the National Academy and the Indian Academy of Sciences.

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(*Issued 30th April, 1947*)

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SECOND SYMPOSIUM ON THE AGE OF THE SALINE SERIES IN THE SALT RANGE OF THE PUNJAB

Held under the joint auspices of the National Academy of
Sciences and the Indian Academy of Sciences at Udaipur,
27 and 28 December, 1945.

PROCEEDINGS.

The meetings were held in the Chemistry theatre of Bhupal College, Udaipur.

Professor B. Sahni, president of the National Academy of Sciences, opened the discussion with an address on "Microfossils and the Salt Range Thrust." Among others present were Rajadhiraj Harisinghji of Achrol; Sir C. V. Raman (Bangalore), president of the Indian Academy of Sciences; Professor K. S. Krishnan (Allahabad), president elect of the National Academy of Sciences; Drs. K. R. Ramanathan and L. A. Ramdas of the Meteorological Observatory, Poona; Professor S. Ranjan, Dean of the Faculty of Science, University of Allahabad; Mr. E. R. Gee, Superintending Geologist, Geological Survey of India (Nok-Kundi, Baluchistan); Dr. M. S. Krishnan, Superintending Geologist, Geological Survey of India (Madras); Mr. J. Coates, Senior Geologist, Burmah Oil Company, Digboi; Dr. C. Mahadevan, Professor of Geology at the Andhra University (Waltair); Dr. V. Sukhatme, Indian Council of Agricultural Research, New Delhi; Dr. T. S. Sadasivan, Director, Botanical Research Laboratory, Madras; Mr. K. Ramiah, of the Institute of Plant Industry, Indore; Dr. K. M. Gupta, Professor of Botany at Dungar College, Bikaner; Dr. V. Puri, Professor of Botany at Meerut; Mr. M. S. Mani, Lecturer in Zoology at St. John's College, Agra; Dr. R. V. Sitholey, Mr. B. S. Trivedi and Mr. R. N. Lakhanpal of the University of Lucknow.

Cyclostyle copies of all papers received by the 22nd of December, 1945 had been sent in advance to all contributors in India and abroad.

After the opening address by Professor Sahni, Mr. E. R. Gee, Dr. M. S. Krishnan, Mr. M. S. Mani, Dr. R. V. Sitholey, Mr. B. S. Trivedi, and Mr. R. N. Lakhanpal presented their papers. The remaining contributions, of which the authors were unable to attend the meeting, were taken as read but were briefly reviewed by Professor Sahni. The General Discussion then followed.

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MICROFOSSILS AND THE SALT RANGE THRUST.

By

B. SAHNI, Sc.D., F.G.S., F.R.S.,

PROFESSOR OF BOTANY, UNIVERSITY OF LUCKNOW

(Opening address at the Second Symposium held at Udaipur on 27 and 28 December, 1945 under the joint auspices of the National Academy and Indian Academy of Sciences).

(With 11 Plates and 36 Figures in the text).

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1. INTRODUCTION; RESULTS OF THE POONA SYMPOSIUM, 29-30 December, 1944.

At the end of our Poona meeting geological opinion based upon the field evidence was still sharply divided, while the palaeontologists were all in favour of a post-Cambrian age for the Saline Series. The angiosperm remains proved that the Series cannot be older than Jurassic, while several of the insect fossils indicated an age not earlier than Tertiary. Considered in the light of the stratigraphical position the fossil evidence definitely pointed to an Eocene age, and this conclusion was not contradicted by what was already known of the distribution of heavy minerals.

Although the balance of evidence thus distinctly favoured the idea of an Eocene Saline Series overthrust by the Palaeozoic strata, it was agreed that there was still room for the collection of further data of critical value. The following suggestions were made :

- (a) *The fossil evidence should be made more convincing*
 - (i) by the discovery of *macrofossils* and, if possible, by confirming Anderson's find of *Quercus* leaves in the Khewra gorge;
 - (ii) by preparing *microfossils* from further samples of *dolomites* and *oil shales* collected by the geologists of the Cambrian school;
 - (iii) by the *microfossil investigation* of rocks taken from deeper levels, e.g., by excavation of outcrops, or from borings;
 - (iv) by the examination of *test samples of known geological age*, as a check against the contamination theories of Fox (through solution and re-deposition) and of Gee and Lehner (through micro-cracks);
 - (v) by examining a series of rocks taken from below upwards in the Salt Range sequence, in order to see where, in that sequence, microfossils of the Saline Series type (especially angiosperms and insects) cease to appear.
- (b) *The field evidence should be more critically examined*, particularly the nature of the disputed junction between the Saline Series and the

overlying Palaeozoic rocks in Mr. Gee's critical sections in the Dhodha Wahan, and east of the Warchha Circuit House. In this connexion the "sheared" *Talchir boulders* which Mr. Gee had once used in support of the overthrust theory should also be closely examined.

2. THE EXCURSION OF OCTOBER 1945:

COMMENTS AND ORIGINAL OBSERVATIONS.

In October 1945 Mr. Coates and I were conducted by Mr. Gee on a fortnight's tour of the Salt Range, from Kalabagh on the Indus to Jalalpur on the Jhelum, near the eastern end of the Range.

At both these ends the geology is dominated by tectonics on an imposing scale. Between the two rivers the 100-mile loop of the Range forms a sinuous fringe which bulges in a curious (one might almost say unexpected) manner, not northwards but to the south. This broad loop, and its connexion with the Trans-Indus Range through the sweeping curve of the Mianwali re-entrant, gives the whole Range an alignment quite foreign to the mountain trend lines in this corner of India, which as a rule strike in a general N.W.-S.E. and N.E.-S.W. direction.

That remarkable fracture point at Jalalpur, where the Range takes an abrupt turn to the north; the S.W.-N.E. alignment of the Jogi Tilla ridge with its imbricated thrust-structure; and the curious meridional course of the river Jhelum for a hundred miles from Domel southwards as far as the city of Jhelum, are all features which fit in well with the idea that this corner of the southwardly thrust Potwar sheet has encountered an obstacle from the south and east.

In the western part of the Range, stretching N.W. up to Kalabagh, we see a reflexion of the same idea, though in a less striking form, in the great bend of the alignment round Warchha Mandi, and in the evidences of strike faulting and thrusting, here more frequent than in the middle part of the Range.

On its southern scarp face, but particularly in the many gorges that traverse the Range north to south, are exposed magnificent sections from the early Cambrian to the Tertiary; and lucky is the geologist whose duty or pleasure calls him to this celebrated area, for this is a veritable museum of field geology, and some of the exposures are a fossil hunter's paradise.

At Khewra we were met by Messrs. Lamba and Pinfold, and it was possible (apart from visits to the Salt Mine and the gorge) to make a trip to the Salt inlier at Kallar Kahar, on the fringe of the Potwar Plateau. From Warchha visits were paid to the Fatehpur Maira gorge and to the Chittidil-Sakesar-Amb area, where the important sections on the slopes of the Dhodha Wahan were carefully examined. On the morning of the 25th October a motor drive from Khewra to Jalalpur, parallel to the sunlit scarp face, afforded an unforgettable passing show of some of the main features of Salt Range stratigraphy. Among these, a few miles west of Jalalpur, were the clearly exposed imbricated thrusts repeating parts of the Cambrian sequence upon itself with its basal member, the Purple Sandstone, resting directly upon the vividly coloured "Red Marl"—a type of structure which Mr. Wadia (1945 pp. 214-221) has described on a grander scale in the Jogi Tilla, further to the north and east.

In his more detailed account of the tour Mr. Gee will comment upon the many sections we examined. I shall here confine myself to some of the salient points that seem to call for remark, with special reference to the subject of our discussion.*

**Postscript:* The unexpected delay which this volume has suffered at the hands of the Printer enables me to record also my impressions of another excursion to which Mr. Gee very kindly invited me in November, 1946. Some of the photographs here reproduced were taken on this occasion, and further material of rock-samples was collected.

On 28 November I met Mr. Gee, Mr. J. B. Auden and my brother Dr. M. R. Sahni at Khewra. Motoring by the Pidh road past Dandot, we crossed the Range to Choa Saidan Shah and then westwards, roughly along the strike, through Kallar Kahar, Bhuchal, Nurpur and Bhadrar to Jaba, from where we descended south-eastwards across the Range to reach Katha and Khushab, in the plains. The next day we drove to Gunjyal and on to Chhabil, thence walking up to Chittidil where we were joined by Dr. G. M. Lees of the Anglo-Iranian Oil Company who was then temporarily in India, Mr. B. S. Downward of the Burmah Oil Company and Mr. W. D. Gill of the Attcock Oil Company. After four days spent in examining the important sections on the slopes of the Dhodha Wahan we walked up the Salgi Wahan, on the way examining an oil seepage, then over the ridge into the Fatehpur Maira gorge, and back to our cars at Chhabil. On 3 December we motored back to Khushab and Katha, this time crossing the Range up the Kalra Wahan to Bhadrar, and then eastwards as far as the Pidh road section near Dandot. From here Mr. Gee, Dr. Lees and I walked across to the Khewra gorge and back to our starting point, *en route* examining the section of the Upper Gypsum Dolomite Stage (Anderson's *Quercus* locality) where the Saline Series lies with a shattered junction beneath the Purple Sandstone. On 4 December I paid another visit to this section, mainly with a view to search for macrofossils, which proved fruitless.

The valuable opportunities of discussion which these two excursions afforded me will remain for me a memorable experience for which I shall always be grateful to my colleagues; apart from this, I shall recall with pleasure the many personal kindnesses I received, particularly from Mr. Gee.

(a) *The Saline Series at Kalabagh (October 13, 14).*

Our time did not allow a visit to the interior of the Kalabagh Salt Mine, but from a dump near the mine mouth, on the right bank of the Luni Wahan, I collected samples of the salt marl (S. 41, October 13), which here is of a somewhat darker, chocolate red, colour than that of Khewra and Warchha. This material has not yet been examined for microfossils, nor need we attach importance to any organic remains that may turn up in such a sample, coming from an unknown stratigraphical position.

Close to the right bank of the Indus, on the southern slopes of Kalabagh Hill, are exposed a series of well bedded, often more or less pitted but in places quite compact and laminated grey dolomites, which strongly remind one of the dolomites in the Warchha gorge. At the same locality were found loose bits of the hard, black-and-white banded cherty dolomite, also found in the Warchha gorge; but in our rapid traverse no outcrop of this banded rock was met with. Two blocks of the compact grey dolomite (S. 42a, S. 42b, October 13), taken from horizons a few feet apart, have been examined in dilute HCl, but their behaviour was somewhat unexpected after my experience of the Warchha dolomites. The rock shows very little effervescence, even when the flask is heated and stronger acid (up to 30%) is used. No microfossils were to be found in the meagre solution obtained. The examination, however, should be carried further, and other samples from the same locality should be analysed; it would be wrong to draw any inference, one way or the other, from this incomplete test.

We did not visit the locality ("in a tributary, half-a-mile N.W. of Kalabagh, in the Lower Gypsum-Dolomite stage of the Saline Series") from where the kerogen shale described by Dr. A. Lahiri was collected several years earlier. In view of the well stratified carbonised remains lying parallel with the bedding of the shale, which Lahiri has figured (1945 pp. 329-334, Photo. 3), it would be important to subject samples from here to careful micro-examination. Lahiri's work was, of course, not directed to the palaeobotanical aspect, and until his "carbonised twigs and microspore cases" (p. 334) are described and figured we must admit the criticism that in this case a post-Cambrian age has not been proved on *fossil evidence*.

I am therefore unable at present to express any view on the age of the Saline Series of the Kalabagh area.

(b) The Talchir Boulder Bed—Saline Series junction near Daud-Khel (Oct. 14).

In the Daud Khel area just north of the Jaba Nala the Talchir Boulder Bed, here tilted at a high angle, directly overlies a red gypsiferous saline marl. Here again the position seems to me still rather vague and unsatisfactory. Mr. Gee was inclined to regard this contact as an undisturbed though unconformable sedimentary junction, and the marl therefore definitely as pre-Talchir. He argued that the lower part of the Boulder Bed was unlike the higher parts in its reddish chocolate colour, which he would derive from the underlying red marl. He further pointed out that (in addition to the usual hard Talchir boulders of granite, quartzite etc., about which I shall have more to say presently) the lower part of the glacial matrix contained many boulders of gypsum, one of them as big as 12 feet by 8 feet.

According to Mr. Gee this gypsum must have been derived by erosion from the underlying formation which he regards as Cambrian or older. While admitting that gypsum of known Eocene age also exists in the close vicinity, he separates the two by their colour and lithology. One would wish that the case for the difference in age rested on more substantial grounds. Colour differences and lithology have too often proved deceptive and one might well hesitate to use them as critical evidence. It is not inconceivable that the reddish colour of the basal part of the Boulder Bed was derived by the upward diffusion of solutions across an *overthrust* contact. Part of the gypsum might have been incorporated into the Boulder Bed during its translation across a gypsiferous formation. Cannot a tectonic contact between two formations like a glacial tillite and a saline marl, both of them here essentially devoid of stratification, have become so masked, in the course of geological time, as to retain no outward evidence of its real character?

I looked in vain for any compact strata, such as dolomites or oil shales, for a microfossil test; as for the gypsum, it has so far proved intractable material for such treatment. In the absence of any fossil evidence I am unable to risk an opinion on the age of the marl here.

(c) The "sheared" Talchir Boulders at Daud Khel (Oct. 14) and Chittidil (Oct. 18 to 20).

I come now to the "sheared" Talchir boulders. You will recall that at one time Mr. Gee (1934) had used these as an important plank in his case for a regional overthrust. It was therefore with keen expectation that I viewed the first specimens to which he drew my attention at the section we have just

been discussing. Many others were later seen elsewhere, particularly in the magnificent exposure on the slopes of the Dhodha Wahan between Chittidil and Ratta, where the Boulder Bed attains a thickness of 200 to 300 feet (Plate 1, Photo A).

I carefully examined all the boulders that came my way, from the point of view of the thrust idea, but I confess I am somewhat surprised that they should ever have been used in support of that view, which I think is well established on other grounds. The boulders did not reveal anything like the picture I had been led to form after reading Mr. Gee's original account—a single clean split across the boulder, with the two smooth faces slipped apart as if by a strong shearing force acting parallel to the plane of fracture. On the contrary, I noticed many of the boulders badly shattered, as if by a vertical crushing force, or cracked, perhaps by frost action. It was noteworthy that even tiny boulders, barely an inch across, were cracked: it is hard to imagine that these could have been so gripped in a plastic matrix as to be split across by a thrusting or sliding force. The fracture surfaces, moreover, were not in the slightest degree planed or polished, striated or slickensided so as to suggest slipping of one piece over another, but showed the rough grain of a typical fractured rock surface, such as you produce with a hammer blow. Sometimes a large boulder shows several fractures, and these tend to spread out fanwise, yielding wedge-shaped pieces; and it is significant that as a rule the fragments hang together wherever the boulder lies firmly embedded in the matrix. Lastly, as Dr. Lehner explained to us at Poona (First Symposium p. 316) the fractures have no relation to the presumed plane of thrusting: as a rule they are vertical or nearly so (Plate 3, Photo F). I cannot recall having seen a single boulder fractured parallel to the plane of the junction. Dr. Lehner was, of course, speaking against the idea of a *regional thrust*, but was inclined to relate the supposed shearing to relatively young cross-faults which might have offset the junction between these two formations. And in reply to a question he went on to explain:

‘To the suggestion that the boulders might originally have been sheared in conjunction with a Talchir-Saline Series thrust and have been twisted round subsequently I might reply that I consider such a coincidence highly improbable.’

With this reply I fully concur; but, having now seen the phenomenon for myself, I would go even further: I do not think the fractures are due to any faulting or thrusting forces at all, whether regional or local. They appear to be the familiar result of temperature variations in an extreme climate, subject

to frosts by night and a burning sun by day. It may be useful to do a little digging to see if boulders buried deep within the tillite, away from frost and sun effects, are similarly cracked¹.

(d) *Warchha and Chhabil (Oct. 15 to 17): The Purple Sandstone-Saline Series junction.*

Our next visit was to Warchha. Here the critical junction is clearly exposed in the section east of the Circuit House, where the Maroon Shales and Flags rest directly upon the top-gypsum of the Saline Series which caps the Red Marl. The lower part of the Maroon Shales includes many thin bands of gypsum which pass below into the top-gypsum in a manner which no doubt suggests a conformable passage. But, on the other hand, might not the Maroon Shales represent the sole of an overthrust column of strata which have incorporated part of the gypsum over which they moved?

In discussing similar sections in the Chittidil-Sakesar-Amb area Mr. Gee says that similar "thin bands of gypsum 1/8 to 1/4 inch thick occur along the bedding planes of the lower maroon shales and flags". And he adds that "Although this latter gypsum may be *in situ* in the Purple Sandstone Series as it appeared to be at Warchha, it might also have been brought up in solution from the top gypsum beds of the underlying Saline Series". It is not clear why the same explanation cannot apply to the gypsum bands in the Circuit House section.

No dolomites or oil shales were observed in this section, but we have ample published evidence of post-Cambrian microfossils from the Salt Marl, Dolomites and Oil Shales of several other localities in this gorge (Sahni, 1945) and from the Salt Mine (1944). Some of these fossils are now illustrated in photographs (see Plates 8, 9, 10).

Another very clear section showing the Saline Series—Maroon Shales junction is seen at Chhabil, a mile S. E. of Chittidil (Plate 1, Photo B; Plate 2, Photos C,D)².

¹ It is quite thinkable that with the stresses and strains they must have suffered on their rough journey from a distant home, the Talchir boulders may have been rendered more susceptible to frost action on being re-exposed. From this point of view it may be interesting to examine some of them in thin sections, for possible microscopic strain effects, and compare them with their corresponding parent rocks in Rajputana taken from the interior of outcrops.

² A sample of dolomite from here, collected on 29th November, 1946 (S. 97) is being examined for possible microfossils by Mr. R. N. Lakhanpal.

(e) *Microfossils from Oil Shales in the Fatehpur Maira Gorge (Oct. 17).*

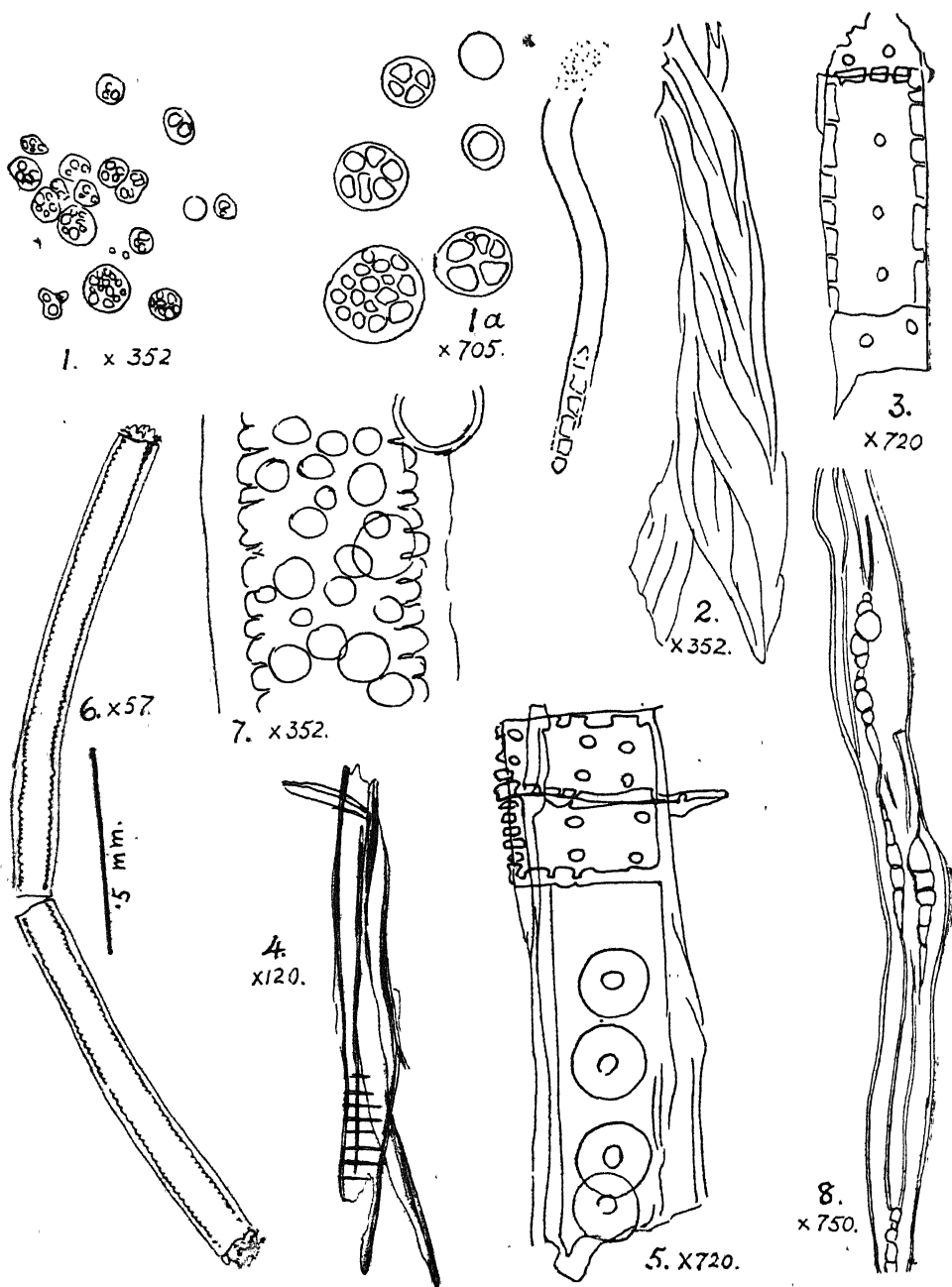
Walking along the foot of the scarp in the direction of Chittidil, we made a short détour into the Fatehpur Maira gorge, where there is a series of Dolomites, Gypsum and Oil Shales well over 100 feet thick, dipping at a high angle and corresponding in stratigraphical position to the Oil Shale Group in the Warchha Gorge. Both belong to the Lower Gypsum-Dolomite Stage, and both include a well marked type of chocolate Oil Shale of low specific gravity which smells of petroleum when freshly broken, sounds like lignite under the hammer, decrepitates when heated in a flame, and is freely combustible.

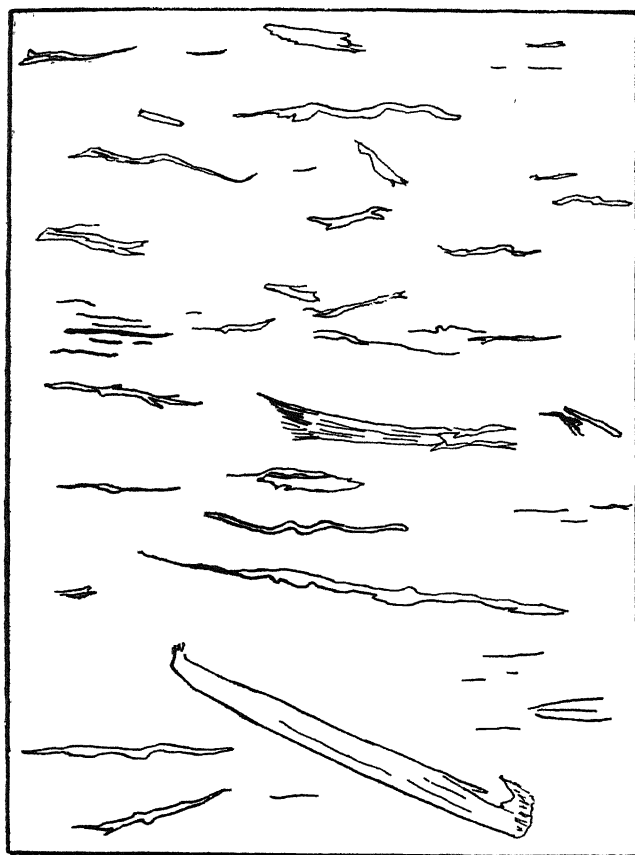
The dark stratum of Oil Shale indicated by an asterisk in Plate 4 Photo H¹ is of special interest because it is extremely rich in shreds of woody tissue. In thin sections of this rock, cut vertically to the stratification, the woody fragments are seen to lie in great numbers, mostly parallel to the planes of bedding (Plate 9 Photos. 9, 10; Pl. 11 Photos 19 to 21 and Text-figs. 8, 8a), appearing like thin, almost transparent strips or lines against the dark brown matrix of the shale. The strips as seen in such a section vary in length up to about 660 μ , frequently extending in a curved or even sinuous course, and they often show frayed ends or margins. In thickness they generally do not exceed 40 μ , but the outlines of the individual wood fibres (or tracheids) can often be made out. Some of the shreds reveal clearly the structure of coniferous wood as seen in a tangential section of the stem, while others are almost certainly dicotyledonous. With aqueous safranin it has been possible to show up the individual shreds of wood as red streaks in the brown rock-matrix.

The fragment shown in Plate 9 Photo 10 and Text-fig. 8, one of the best preserved so far discovered, shows several medullary rays cut across so as to show their uniseriate nature, characteristic of most conifer woods. The outlines of the individual medullary ray cells are perfectly clear, but the pitting is not preserved.

In another vertical section of this oil shale a narrow horizontal strip, about 8 mm. long and .16 mm. thick, is almost entirely composed of woody shreds which appear to have been formed by the crushing of a single piece of wood (Plate 11 Photos 19-21). The structure of this wood strongly suggests a dicotyledon (Photo 21). In places there are black masses of bituminous matter in close contact with shreds of wood, which are sometimes seen more or less enveloping, in other cases passing right through, the bituminous matter.

¹ Photograph H on Plate 4, like several others now published, was taken during a recent excursion (November-December, 1946) when I had occasion to accompany Mr. Gee, Mr. Auden, Dr. G. M. Lees and other geologists.





8a. $\times 90$.

Text-figs. 1-8. Microfossils from Oil Shales in the Fatehpur Maira gorge. Specimen S. 57 (coll. E. R. Gee and B. Sahni 17th October, 1945). from the dark band marked* in Pl. 4, Photo. H). 1 to 7 Recovered after treatment with Schulze's mixture. 8, 8a *In situ* in a thin section.

1. Small alga-like (?) bodies of unknown affinity. (Prepared on 9th December, 1945) $\times 352$.
- 1a. The same; also a filament of an unknown organism. $\times 705$.
2. A shred of disorganised wood showing spiral texture. (Prepared on 12th December, 1945). $\times 352$.
3. A pitted woody cell. (Prepared on 12th December, 1945). $\times 720$.
4. A piece of wood with a medullary ray. Pitting obscure. (Prepared on 17th December, 1945). $\times 120$.
5. Coniferous wood with a medullary ray in radial section, with pitting of the abietineous type. (Prepared on 11th December, 1945.) $\times 720$.
6. A large straw-coloured cylindrical body (? chitinous, possibly a vein from an insect wing?). Within a firm hyaline sheath was a softer cylindrical core of white colour, marked with fine reticulations giving a transversely striated appearance. (Found on 16th December, 1945, after the material had been for 12 days in Schulze's mixture). $\times 57$.

The great abundance of these microfossils and their distribution along the bedding planes is well shown by Plate 9 Photo 9 and Plate 11 Photos 19-21. In Photo 9 there are, on the average, about 17 fragments of wood in a square millimetre of the area of the section. These photographs leave no room for doubt that the fossils are strictly *in situ* and contemporaneous with the time of formation of the shale.

The combustible nature of the rock can only be traced to the decomposition of these organic remains, which must be regarded as the *Urmaterial* of the oil in these rocks of the Saline Series.

Apart from this crucial evidence of microfossils seen *in situ*, numerous other fossil remains were recovered by maceration in Schulze's mixture (conc. HNO_3 and KClO_3). Here is a brief account of a single small sample. Thin slips of the rock were (on 4 Dec. 1945) ground on all faces, passed rapidly through a gas flame, and then kept in filtered HNO_3 to which some freshly re-crystallised KClO_3 was added. After two or three days the rock turned a light yellow brown and could easily be crumbled to a powder. On the 9th December a peculiar filamentous body and numerous small spherical bodies like colonial algae were brought up in a pipette (Text-figs. 1, 1*a*). I have no idea of the affinities of these fossils. On the 11th a well preserved piece of coniferous wood with unmistakable abietineous pitting was sucked up in the same way (Text-fig. 5), and the next day appeared the woody shreds shown in Text-figs. 2 and 3. On the 17th December a considerably larger shred of wood (Text-fig. 4) was found. But the largest fossil discovered, at least 2 mm. long and easily visible to the naked eye, was the long cylindrical fragment shown in Text-figs. 6 and 7. This was found on the 16th December. It had

-
7. The same. The numerous minute bubbles (produced by the core on pressing the preparation under a coverglass) lie mostly between the core and the sheath. $\times 352$.
 8. Shred of wood tissue, probably coniferous, in tangential section, showing several well preserved uniseriate medullary rays cut transversely. *This fragment is one of thousands seen actually embedded in the oil shale on cutting the rock vertically to the planes of bedding. The woody shreds nearly always lie parallel to the planes of bedding (see Pl. 9 Photo 9 and Text-fig. 8*a*).* $\times 750$.
 - 8*a*. Camera lucida sketches from a thin section of Oil Shale cut vertically to the planes of bedding (*which run horizontally but are not indicated in the figure*). The fragments of wood were sketched from selected parts of a single section, to show their varying size and shape, as well as the positions they occupy with respect to the stratification of the rock (compare Pl. 9, Photo. 9). Their frequency of occurrence is substantially the same as shown in this group. $\times 90$.

resisted maceration for twelve days, and appeared to be of chitinous nature : possibly it is a vein from an insect wing, but this is only a conjecture. I cannot compare it with any plant structure that I know. This fossil would be of no value as an age index, were it not for the fact that a very similar type of cylindrical chitinous fragment with a hyaline sheath has been found in a sample of Tertiary shale from a bore-core in the Barail Series of Assam (Plate 11 Photo 24). This was discovered by Mr. Trivedi during microfossil investigations recently undertaken in my laboratory for the Burmah Oil Company, with a view to correlate horizons within the oil-bearing Tertiary rocks of Assam. Another fossil *identically of the same type as this Assam specimen* was recovered by Trivedi from a sample of Rocksalt and Kallar from a tunnel in the Warchha Salt Mine (Plate 11 Photo 23).

These microfossils in the Fatehpur Maira Oil Shales cannot easily be explained away. Even if it were possible to argue that those prepared by maceration may have been "contaminations" (which it would be extremely difficult to do), those that we see in hundreds in a single thin section of the rock, lying perfectly interstratified with the laminae of the shale, would make any such interpretation out of the question.

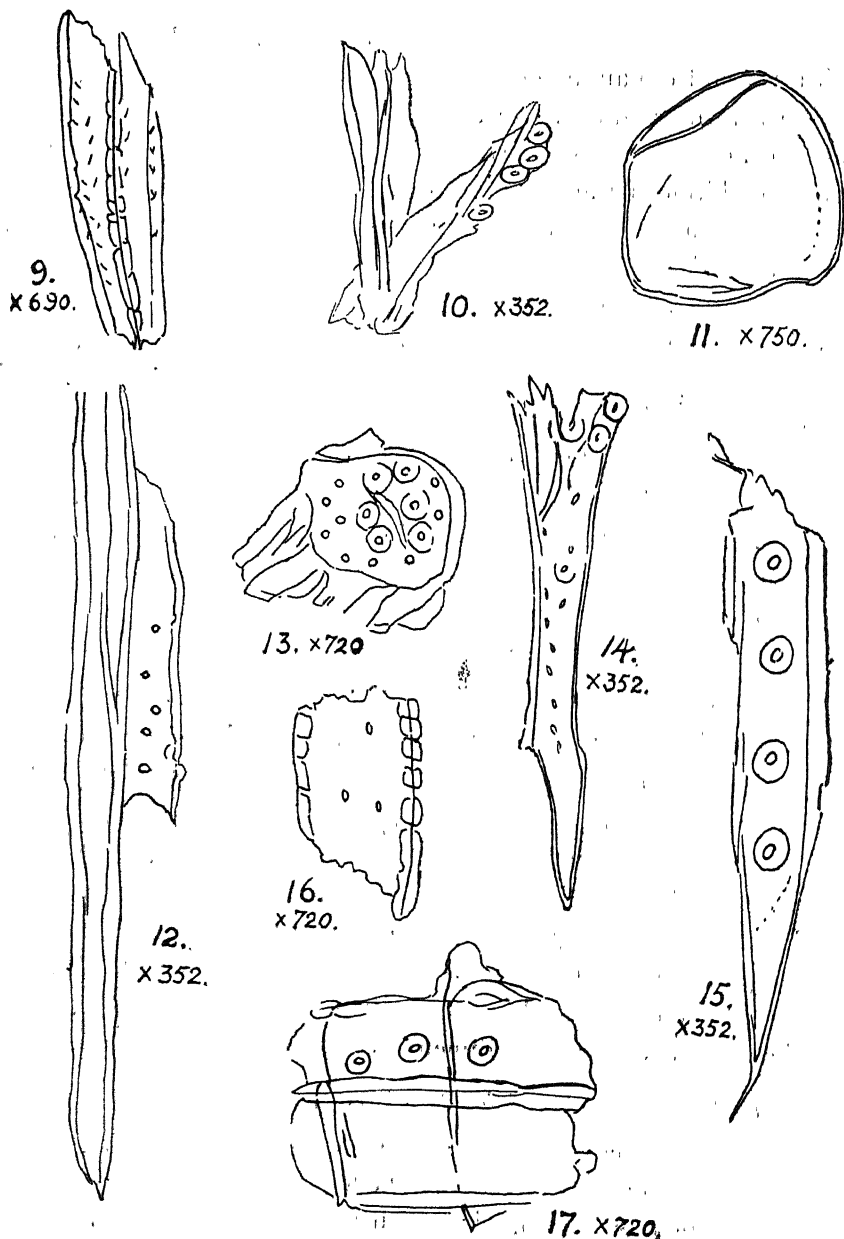
(f) *Microfossils from the Chittidil—Ratta area, Dhodha Wahan (Oct. 18-20).*

The sections in the Dhodha Wahan, where the Talchir Boulder Bed lies with an apparently undisturbed and regular contact over various stages of the Saline Series, have already been briefly discussed above. Mr. Gee finds that where the Boulder Bed rests upon the grey dolomites, the lower part of that bed frequently has a lighter colour than higher up; just as in the Daud Khel section the lower part of the Boulder Bed, resting upon the Red Marl, has somewhat more of a reddish colour. This fact is cited in support of the view that these contacts are of a sedimentary nature, not tectonic planes.

(i) *Microfossils in Dolomites, West of Ratta.*

Because Mr. Gee regards these sections in the Dhodha Wahan as critical, the Dolomites (and the Oil Shales interbedded with them) were examined with special care for possible organic remains, and here is the result.

From a sample of the 8 ft. thick dolomite, exposed in a section $1\frac{1}{2}$ miles west of Ratta, a dozen pieces with freshly broken faces were first passed through a flame, to destroy any adhering extraneous organic matter, and plunged into a jar of 12% HCl, in which they showed vigorous effervescence. About 20 freshly broken fragments of the white and pinkish 30 ft. thick dolomite,



Text-figs. 9-17. Microfossils from Dolomites in the Dhodha Wahan, recovered after treatment with 12% HCl. (Coll. E. R. Gee and B. Sahni, 20th October, 1945). 9 is from an 8 ft. thick band of compact grey dolomite in the top of the Saline Series, directly underlying the Talchir Boulder Bed, $\frac{1}{2}$ miles west of Ratta, Dhodha Wahan. Specimen S. 68—S. R. E. 121.

10-17 are all from a specimen of white and pinkish dolomite from the 30 ft. thick stratum in the top of the Saline Series, directly underlying the Talchir Boulder Bed, in a ravine 5 furlongs west of Ratta, Dhodha Wahan. (See Plate 3, Photo. E). Specimen S. 70—S.R.E. 113.

exposed about 5 furlongs west of Ratta (Pl. 3, Photo. E), were similarly treated and they behaved in the same way. From time to time during the week or ten days following this treatment, a large number of woody fragments, and a spore-like body, were recovered from the rock solutions (see Text-figs. 9-17). The legends attached to the camera-lucida sketches should make any further description unnecessary. The abundance of woody tissues in one of these samples will at once be evident from the fact that a single drop of the rock solution (examined on 11 December, 1945) brought forth all the microfossils shown in Text-figs. 13 to 17, besides others that have not been figured.

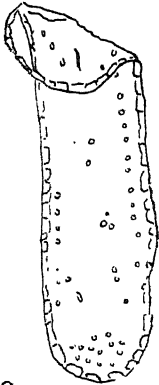
Most of the woods must be coniferous, but one or two (with simple pits) may belong to angiosperms. The occurrence of these groups of plants at once rules out a Cambrian age for the dolomites.

I may say at this stage that, in most cases, the microfossils discovered in the rocks of the Saline Series are intrinsically of no special interest. For this reason the search was not pursued further after evidence of their occurrence in each rock sample was established beyond doubt by the discovery of a few well defined specimens referable to groups of known post-Cambrian age. The number of specimens actually recorded here is thus no index of their relative abundance in a rock-sample. As a rule, from each rock-sample, only a few tiny bits totalling not more than two cubic centimetres in volume, were taken for treatment; and in most cases the very first drop or two of the rock solution showed evidence of microfossils. This will give you some idea of the quantity of fossil material that must be contained in the rocks. Once the fossiliferous nature of the sample was established the rest was only a

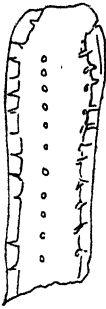
-
9. Shred of pitted wood (found on 8th December, 1945). $\times 690$.
 10. Fragment of wood with elliptic bordered pits (found on 11th December, 1945). $\times 352$.
 11. Spore-like body (found on 8th December, 1945). $\times ca. 750$.
 12. Piece of wood with simple pits (found on 7th December, 1945). $\times 352$.
 13. Fragment of wood with one cell showing crowded bordered pits and some (?) simple pits or, more probably, pits with obscurely preserved borders (found on 11th December, 1945). $\times 720$.
 14. Tracheid with bordered pits, mostly with obscure borders (found on 11th December, 1945). $\times 352$.
 15. Tracheid with bordered pits (found on 11th December, 1945). $\times 352$.
 16. Woody cell with simple pits (found on 11th December, 1945). $\times 720$.
 17. Woody tissue with bordered pits (found on 11th December, 1945). $\times 720$.

The fossils shown in Figs. 13 to 17, and a few more (not figured) were all discovered in a single drop of the rock-solution.

The Age of the Saline Series in the Salt Range (Second Symposium).



18. x720.



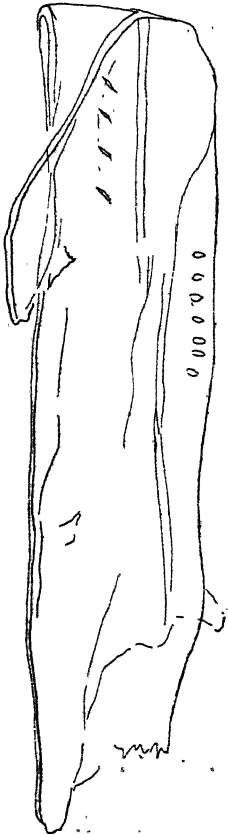
19. x560.



20.
x720.



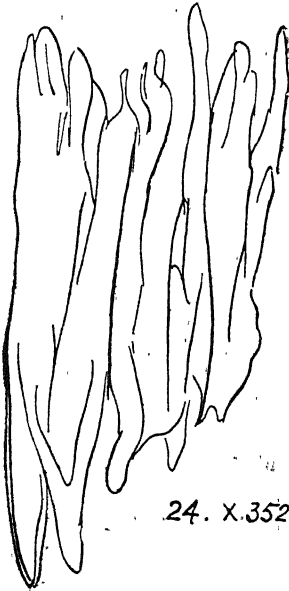
21 x560.



22. x352



23. x117.



24. x352.

question of searching for a few well characterised microfossils for the purpose of illustration.

The above statement applies to the samples of Kallar and Dolomite as well as to the Oil Shales, but the Fatehpur Maira Oil Shale (S. 57) is exceptionally rich in microfossils.

(ii) *Microfossils in Oil Shales (? and Bituminous Dolomites) West of Ratta.*

Directly below the massive 30 ft. Dolomite just mentioned are some well bedded cherty Dolomites, at least 4-5 feet thick (Pl. 3, Photos. E and G) within which there are thin intercalations of dark Oil Shales (S. 71=S.R.E. 115, coll. E.R. Gee and B. Sahni, 20 October, 1945). Although vaguely described as oil shales these intercalations also contain small ellipsoidal pellets which appear to be dolomitic. Some freshly broken pieces of this sample, ground on all sides to remove all pits or cracks, were (on 13th December, 1945) passed through a flame, and some of them were immersed in 12% HCl, others in concentrated HNO₃, both acids having been carefully filtered beforehand through sintered glass.

There was vigorous effervescence in the nitric acid jar and within less than 15 minutes a drop of the acid examined under the microscope showed the fragments of pitted wood sketched in Text-figs. 19 and 21.

The fragments treated with dilute HCl brought forth the microfossils shown in Text-figs. 22-24 (on December 15) and those shown in Text-figs. 18 and 20 (on December 16).

After this convincing evidence of post-Cambrian fossils it was considered unnecessary to pursue the search any further.

Text-figs. 18-24. Microfossils from thin Oil Shales interbedded with cherty dolomites immediately below the 30 ft. stratum of Dolomite in the upper part of the Saline Series, 5 furlongs west of Ratta (See Plate 3, Photo G). Specimen S. 71=S.R.E. 115 (coll. E. R. Gee and B. Sahni 20th October, 1945).

18. Woody cell with numerous small simple pits (found on 16th December, 1945). \times 720.
19. Thick-walled woody cell with simple pits (found on 13th December, 1945). \times 560.
20. Pitted woody cell (found on 16th December, 1945). \times 720.
21. Small thick-walled woody cell with simple pits (found on 13th December 1945). \times 560.
22. Shred of pitted wood. The oblique pores placed in a row probably belong to bordered pits (found on 15th December 1945). \times 352.
23. A large fragment of structureless wood (found on 15th December, 1945). \times 117.
24. The same fragment after it was pressed down under the coverglass. \times 352.

Note :—The microfossils in Figs. 18, 20, 22 and 23-24 were isolated from the rock by treatment with 12% HCl only. The rest were prepared by treatment only with conc. HNO₃.

(iii) *Microfossils from the Talchir Boulder Bed near Chittidil.*

It may be of some interest to describe here the result of dissolving two samples of rock from two well defined shaley horizons within the thickness of the Talchir Boulder Bed. The locality is east of Chittidil Rest House, about a mile S. E. of Serai village, as measured on the map (See Pl. 1, Photo. A). The Boulder Bed is here 200-300 feet thick. The samples came from levels about half way between the top and bottom; the exact spot from where they were taken is indicated in the legend to the photograph.

Sample S. 65 A (coll. B. Sahni, 19 October 1945) came from a rather massive band, at least 3 ft. thick, of a brown to grey colour. This band also contains some erratic boulders but they are mostly of small size, and the matrix is much finer than that of the Boulder Bed above and below. After carefully brushing the surface of the sample and rotating it rapidly in a flame, the fragment was plunged (4 December, 1945) into a jar of filtered 12% HCl where it showed effervescence. There was no occasion to examine the solution until 13 days later, when the well preserved coniferous wood (Text-fig. 25; Pl. 10, Photo. 18) was observed.

Sample S. 65 B (coll. B. Sahni 19 October, 1945) was a greenish rock from a thin band just below the first band; it was similarly treated on the same day. This sample effervesced more vigorously than S. 65A. On the 9th December, 1945, a dark chocolate brown, almost black, smooth-walled ellipsoid spore (Text-fig. 27) was discovered, and on the 10th the coniferous wood shown in Text-fig. 26.

I have no doubt that these Talchir rocks are much richer in organic remains than these few plant remains, discovered during a cursory examination, would seem to indicate. They deserve a much more extended investigation than I was able to devote to them while engaged mainly in examining rock samples from the Saline Series¹.

It is significant, however, that while angiosperm remains have turned up frequently in the Saline Series rocks, there has so far been no evidence of them in the Boulder Bed, and this was only to be expected, considering the known Carboniferous age of this Bed. In this respect, therefore, the junction between the Saline Series and the Boulder Bed overlying it forms a sharp palaeobotanical boundary.

¹ One would expect at least some of the many spore forms we now know from other Lower Gondwana rocks in the Salt Range, in the Peninsula and in other Gondwana countries (for references see Sahni 1946). It is to be hoped that someone will undertake a thorough microfossil investigation of the Indian Gondwana tillites for a comparison with those from Australia and South Africa.

Talchir Boulders half embedded in Dolomite near Ratta.—An interesting feature to which Mr. Gee drew attention was the fact that on the exposed upper surface of the 30 ft. dolomite, where the overlying Talchir Boulder Bed has been locally denuded away, some of the Talchir Boulders were seen *half embedded* in the dolomite (see Pl. 3, Photo. F). I am unable to offer an explanation for this curious fact.

Dolomites below the Purple Sandstone at Amb.—In the ravine just below Amb, on the right-hand side as we approach the village by the pony track from Chhabil, the Purple Sandstone overlies some massive Dolomites of the Saline Series, which in places contain cherty looking ellipsoid pellets, occasionally flattened into bands. A sample of this Dolomite (S. 73) was collected for me by Mr. Gee on 20 October, 1945 but has not yet been examined for organic remains. Further samples were collected by myself on 2 December, 1946.

(g) *The Khewra Gorge Section: Anderson's Quercus locality (Oct. 23).*

On the left bank of the Khewra Gorge, less than a mile north of the village, the massive Purple Sandstone rests with its basal Maroon Shales and Flags (here severely shattered) on the upper part of the Saline Series. The Saline Series below the junction consists of white to grey sandy gypseous Dolomites with interbedded thin bands of chocolate Oil Shales, and also an intercalated zone, at least 10 or 12 feet thick, of a heavy, dark purple, jointed rock, the "Khewra Trap".

In Pl. 4 Photo. I the Trap (marked 5) is seen resting on a few feet of greenish grey crumbly porous rock of ash-like aspect (marked 4) which in turn overlies a series of Dolomites and Oil Shales (1, 2 and 3). In another part of the same section (Pl. 5 Photo. J, at 2A) the Trap appears to have been faulted down¹, with its base buried in the stream bed. Here the upper two or three feet of the Trap (Pl. 5 Photo. K, at 2) are full of gas holes, indicating that this is a volcanic lava flow and not an intrusive sheet; and above it again (at 3, 4 and 5) are the same sort of sandy gypseous Dolomites and chocolate Oil Shales as are seen to *underlie* the Trap in Photo. I.

(i) *Futile search for megafossils in Dolomites.*

This is an important area, for it was from here that Mr. R. v. V. Anderson had collected the leaf impression which Professor R. W. Chaney identified as a species of *Quercus*—a fossil which unfortunately is not now accessible for examination. During our visit on 23 October, 1945, therefore, Messrs. Gee, Coates, Pinfold and I made a careful search for similar plant

¹ But a closer examination is required to prove the fault.

remains in the finely bedded Dolomites overlying the Trap (zones 3 and 5 in Photo. K). In this search we had the help of a dozen students who had joined us, but although we all worked for over an hour we failed to discover any megafossils. The thin gypsum partings make it easy to split the dolomite along the planes of bedding, but at the same time they impart a deceptive appearance to the surfaces thus exposed, which are liable to be mistaken for leaf impressions.

These facts, however, do not by any means cast a doubt upon the identification of Mr. Anderson's specimen as an oak leaf; for, as we shall see presently, there is plenty of evidence indirectly supporting his conclusion that the Dolomites are of Tertiary age, so that they might very well contain traces of dicotyledons.

As it turned out, we had been searching at the wrong spot: this we learned only later from Mr. Anderson's paper (printed below) which was not received until December, 1945. The *Quercus* leaf had come from a horizon several metres *below* the Trap at a spot some distance downstream from that where we had been looking for megafossils.

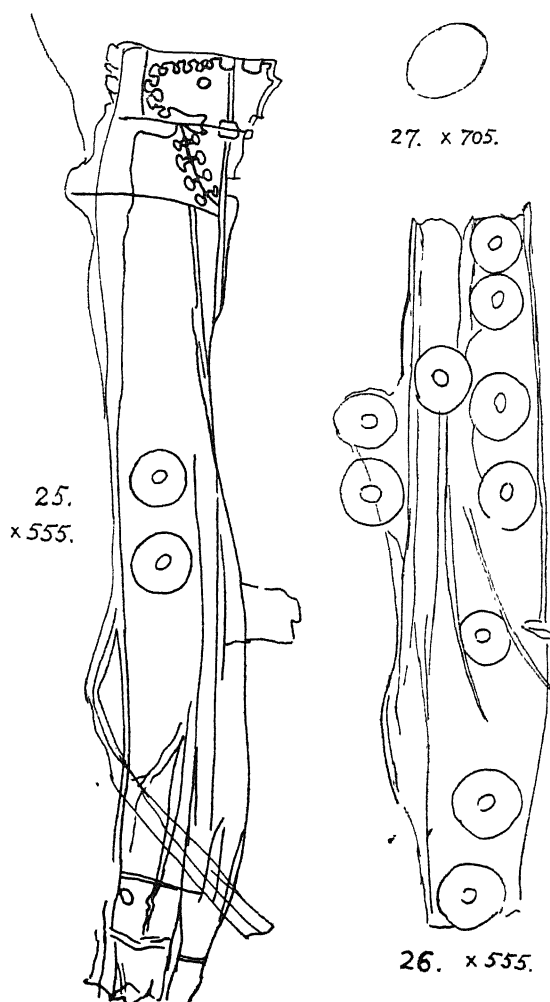
(ii) *Microfossils from Dolomite (Anderson's original rock-sample).*

Through the courtesy of the Director, Geological Survey of India, I was able to examine for microfossils a fragment of rock out of Anderson's original collection from this locality, which he had sent to Calcutta, although the important specimen bearing the leaf impression is not in India. My preparations were passed on to Dr. Sitholey, who also made some further slides from the same material. The microfossils discovered will be described by him separately.

(iii) *Microfossils from Oil Shales in the Upper Gypsum Dolomite Stage, Khewra Gorge.*

While there is thus still room for a further search for megafossils, we need not wait for such a discovery because unmistakable supporting evidence is available from the associated Oil Shales which have yielded both plant and animal remains of undoubted post-Cambrian age.

Messrs. Gee, Pinfold and I collected samples (S. 81) from the thin dark band marked 4 in Photo. K, concerning the *in situ* nature of which no doubt can possibly be entertained. The shale readily splits into papery layers which smell of oil when heated, and easily ignite.



Text-figs. 25-27. Microfossils from calcareous shaley bands within the Talchir Boulder Bed, east of Chittidil Rest House, south of Sakesar. (Or 1 mile SE of Serai village as measured on the map).

25. A piece of well preserved coniferous wood with two medullary rays in radial section, showing abietineous pitting. From a massive grey calcareous band about 3 ft. thick in the middle of the Talchir Boulder Bed (see Plate 1, Photo. A). The rock sample (S. 65A, coll. B. Sahni 19th October, 1945) was taken from the light grey band covered by the left hand numeral 2 in the photograph. (Prepared with 12% HCl treatment on 17th December, 1945). $\times 555$.

26. Coniferous wood with large circular bordered pits. From rock sample S. 65B (coll. B. Sahni 19th October, 1945), a greenish calcareous band immediately underlying the 3 ft. grey band mentioned above. (Prepared with 12% HCl treatment on 10th December, 1945) $\times 555$.

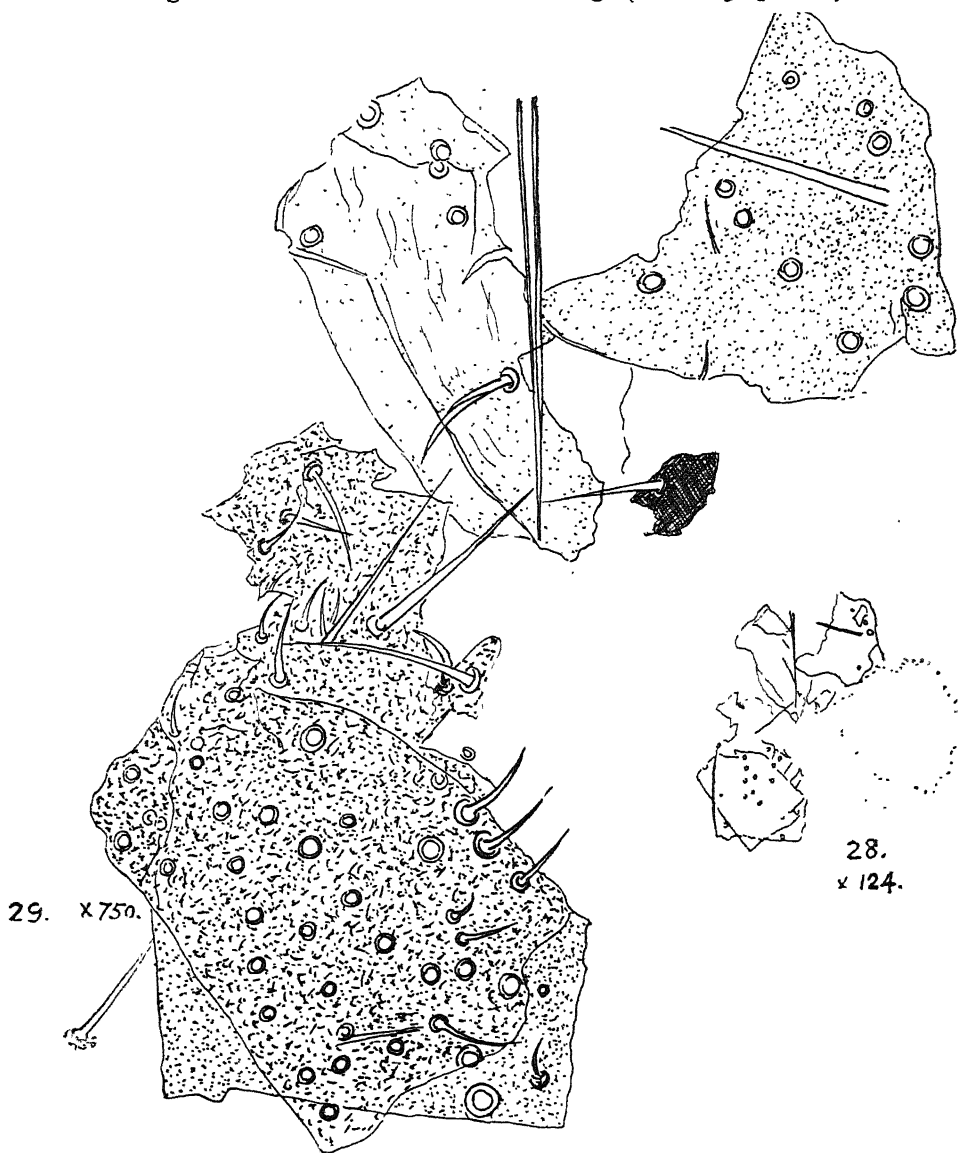
27. Thin-walled ellipsoid very dark chocolate-brown spore with smooth wall, from specimen S. 65B. (Prepared with 12% HCl treatment on 10th December, 1945). $\times 705$.

On 13 December, 1945 some thin slips of the rock were rapidly passed through a gas flame, immersed in filtered distilled water and crushed under water. The coarse brown residue thus obtained was examined at once under the microscope without further treatment. Adhering to one large speck of the rock was a finely stippled amber-coloured membrane which looked suspiciously like an insect chitin. It was partially freed of the mineral matter by rubbing it under the coverglass. By irrigating the fossil, while still under the coverglass, with a little dilute KOH which was sucked out with a piece of filter paper, and again rubbing it by gently pressing the coverglass to and fro, the membrane was made more transparent and was now seen to be formed of two layers which had slipped apart. Both the layers showed up the fine sculpturing and the numerous slightly curved finely pointed setae, many of them still attached in their sockets by their swollen bases (Pl. 8, Photos. 5, 6 and Text-figs. 28, 29). An exact identification of this chitinous membrane has not yet been possible, but Mr. M. S. Mani thinks that there is some resemblance with the genus *Cimex* (Heteroptera). A fuller description is being given by Mr. Mani.

I am indebted to Dr. Sitholey for the two photomicrographs (Photos 1, 2) reproduced in Pl. 8. The further examination of this rock sample was undertaken by him, and he was able to corroborate the post-Cambrian age of the rock by discovering in it an undoubted fragment of pitted wood, of which he is publishing a photograph. This fossil was inextricably mixed up with the dark brown rock-matrix and was unquestionably *in situ* in the shale. Dr. Sitholey will give you a short account of the behaviour of this Oil Shale under treatment.

(h) *Microfossils from Cores, South Pharwala Boring, Khewra Salt Mine.*

At Khewra Mr. Lamba kindly showed us the cores recovered from a boring made below the South Pharwala Section to a depth of over 230 ft. below the floor of Chamber 10. An account of this boring has been given by Mr. Lamba in a brief paper printed below. A series of samples of Rocksalt, Kallar and Dolomite have been examined for microfossils by Mr. R. N. Lakhanpal, who is here to place his results before you in detail, but I may mention briefly that he has discovered woody microfossils as well as chitinous animal remains in dolomitic rocks at 110 ft., 117 ft., 125 ft. and 149 ft. below the floor of the mine chamber, which itself is 525 ft. below the surface and 3,300 ft. from the mine mouth. Further microfossils of the same general character



Text-figs. 28-29. Microfossils from Oil Shales in the Upper Gypsum-Dolomite Stage of the Saline Series in the Khewra gorge. The sample of Oil Shale (S. 81, coll. E. R. Gee and B. Sahni 23rd October, 1945) was taken from the thin dark band covered by the numeral 4 in Plate 5 Photo K.

28. Insect chitin with setae, and scars from which setae have fallen off (prepared on 13th December, 1945). The rock-sample was soaked in distilled water and then treated with dilute KOH only. $\times 124$.

29. The same fragments as above, further magnified to show fine sculpturing of cuticle surface, and well preserved circular scars, some of them lodging pointed setae. $\times 750$.

were recovered from Rocksalt and Kallar from levels 143 ft., 145 ft. and 229 ft. below the floor of the chamber.

Mr. Lakhanpal's work thus affords useful corroboration of the evidence that has come in from various other sources.

(i) *Microfossils from an Exploratory Drift, Bhandar Kas, Khewra Gorge.*

Core samples of Rocksalt and Kallar, recovered from an exploratory drift north of the Bhandar Kas at Khewra, have also been examined by Mr. Lakhanpal. They have again yielded the same type of microflora and fauna, including angiospermous and gymnospermous woods (some of them carbonised), a well preserved grass cuticle, and chitinous remains of unknown animals.

(j) *The Calcareous Tufas of the Salt Range (Khewra gorge, Choa Saidan Shah, Katas, Kallar Kahar, etc.)*

The calcareous tufas of the Salt Range have long been known to amateur fossil collectors who visit Kallar Kahar, Katas and Choa Saidan Shah. The rock is a useful building stone and is locally used as such. At Choa Saidan Shan thick deposits are exposed in the roadside cuttings, often yielding large, well preserved moulds of leaves, stems and roots of flowering plants. Near the freshwater reservoir at the head of the Khewra gorge I noticed (October 23, 1945) two unusually well preserved leaves of a large fan palm. A huge boulder containing good leaf impressions was seen in October, 1944 in the Jarhanwala Nala (Warchha gorge), evidently brought down by a flood. At Amb (20 October, 1945) I collected several good impressions of large dicotyledonous leaves.

The flora of these tufas deserves to be worked out and compared not only with the modern vegetation of the Punjab but also with the known Tertiary flora.

Although the tufa is generally regarded as a recent or sub-recent product of calcareous springs, and at some places similar deposits can be seen today in the process of formation, I have not come across any evidence based upon geological mapping to show that the whole of this formation is of so young a date. It is not impossible that the original deposit may be of Tertiary age and contemporaneous with the Saline Series. My reason for saying so is that while the Eocene rocks of the Salt Range have yielded evidence of an abundant angiosperm flora, the modern vegetation of this desert-like area is strikingly

poor in broad-leaved plants. One would like to know if we cannot trace some of the fossils preserved in these tufas to the same early Tertiary flora which yielded the great quantity of plant material still contained in the Dolomites and Oil Shales of the Saline Series, and which must also have formed the original source of the Salt Range oil, as it no doubt did of the Attock oil.

I am not aware that any palaeobotanist has ever employed the microfossil technique in the investigation of calcareous tufas. The rock is so amenable to HCl treatment that it should be easy to obtain a rich harvest of microfossils, both of plants and of animals. Of course, owing to the spongy nature of the rock special precautions would be required against contaminations. Samples should only be taken from the very cores of large blocks, or from the interior of thick strata freshly exposed by a charge of dynamite.

If a careful geological mapping of these modern-looking deposits (which does not yet seem to have been carried out) shows them after all to be a modern product of springs issuing from the Tertiary limestones, then the origin of the broad-leaved plants, including the big leaves of a fan palm, would demand explanation.

(k) *Kallar Kahar: Salt Marl Occurrence in the Nummulitic Zone (Oct. 24).*

Acting upon a suggestion from Mr. Lamba a visit was paid to the Salt occurrence at Kallar Kahar, of which the true stratigraphical position has been variously interpreted since the time of Wynne.

Mr. Lamba regards the Salt Marl here as being normally interbedded with the Eocene limestones, while Messrs. Gee and Pinfold consider it to be a result of intrusion upwards along a fault plane, essentially agreeing with Wynne's interpretation of 1878.

From the palaeontologist's point of view the outcrop of Red Marl here is disappointing in the extreme: one looks in vain for any dolomitic or oil shale intercalations in which one might hope to find some direct microfossil evidence. In contrast,—almost as if to spite one,—the limestones on both flanks of the narrow strip of the Marl are teeming with fossil shells. One is thus thrown back upon speculation and such indirect inspiration as one can draw from general considerations, in which the personal factor necessarily plays a large part.

From the closely analogous case of the eastern Carpathians Professor R. Zuber (1914) is led to the view that the Salt Range is a southwardly thrust nappe ("eine von Norden her ueberschobene Decke"); and regarding the

age of the Kallar Kahar and similar other salt occurrences along the edge of the Plateau he says that one

“muss durch Annahme von geradezu abenteuerlichen Verwerfungen erklären, um an dem altpalaeozoischen Alter dieser Salzformation festhalten zu können”.

In the absence of positive local evidence one finds relief in comparing parallel instances in other parts of the world. This is what Zuber writes in the light of another such comparison (1914 p. 336):

“Ausserdem gibt es noch eine Reihe anderer fazieller und tektonischer Analogien, auf welche bereits vielfach hingewiesen wurde, und welche vom Himalaja bis zu den Alpen verfolgt werden können, wie z. B. die alpine Trias der Kreidetertiaerflysch, die Nummulitenformation, der gegen die älteren Vorlandmassen vordringende Faltenwurf des jüngeren Gebirge. Alles dies weist auf einen grossartig einheitlichen und heute wohl allgemein anerkannten Bauplan der ganzen geologischen Beschaffenheit des gesamten Mediterrangebietes hin, von welchem doch der fast in der Mitte liegende Punjab wohl keine Ausnahme machen darf.

“Die wunderbare Darstellung des Hazara-Gebirges von Middlemiss (Mem. G.S.I. 26, 1896) zeigt uns ganz unzweifelhaft, dass von dort aus eine Reihe von Deckenueberschiebungen nach Sueden hin ausgehen. Man sieht dies besonders gut am Jhelum an der Grenze von Kashmir.

“Die vereinzelt Nummulitenkalkzuege des Potwar und deren westliche Verlaengierung bis nach Bannu (Trans-Indus) sind nur weitere durch spaetere Denudation zerrissene Ueberreste der Hazara-Decken, welche zum Teil ueber die Murree-Schichten, zum Teil ueber die Salzformation des Kohat Distrikts ueberschoben wurden.

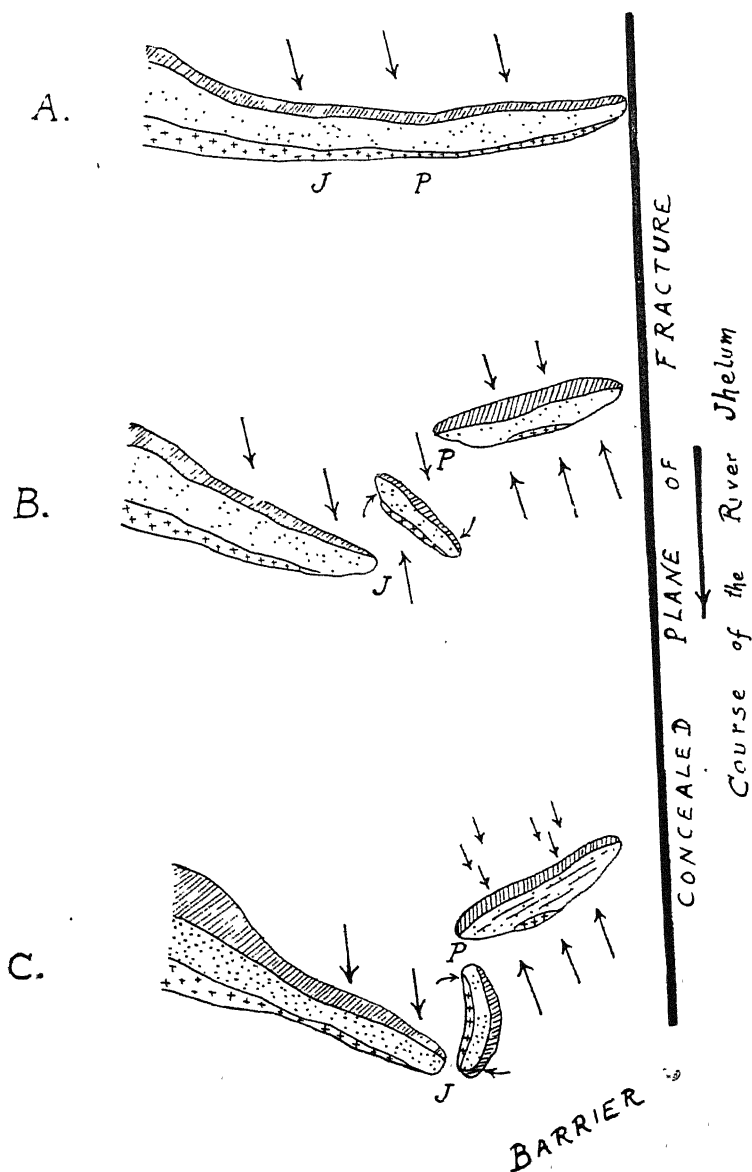
“Der Salt Range kann nur das am weitesten nach Sueden vorgedrungene Glied dieses Faltensystems sein, und seine Salzformation bildet hier wohl dessen autochthone Unterlage von wahrscheinlich tertiaerem Alter”.

(1) *Jalalpur and the Eastern Salt Range (Oct. 26).*

In some respects the most interesting part of the Salt Range is the region round Jalalpur, and to the north and north-east of that point. We have seen that Jalalpur marks an important fracture point beyond which the Range takes an abrupt turn to the north, as the Chambal Ridge. This Ridge again is separated by a second fracture line from the Jogi Tilla Ridge stretching to the north-east.

On a topographical map it appears as if the Chambal Ridge is a simple northward continuation of the Range, swung round to the north with Jalalpur as a pivotal point. That this is not the case becomes clear at once from Mr. Gee's geological map (Gee 1945, Plate 1). There we find that the scarp face of the Chambal Ridge, corresponding to that of the main part of the Salt Range, is not directed eastwards (as it would be if the Chambal Ridge were a simple continuation of the Range swung to the north), but westwards.

How is this remarkable fact to be explained? Can it be due to a swing round of the Chambal Ridge *in the opposite direction*, so that its former western end, which was at Jalalpur, has now been pushed to the north, while its former eastern end, once connected to the Jogi Tilla Ridge, has broken away and has swung round to the south so as to lie at Jalalpur?



Text-fig 30. Diagram of the Eastern Salt Range.
Saline Series shown with crosses; Cambrian dotted; Tertiaries shaded with lines.

This suggestion is here put forward as a purely speculative hypothesis. The relative positions of the main geological formations are shown in an extremely simplified form in the accompanying diagram (Text-fig. 30). Assuming an initially simple southward (or, to be more correct, slightly south-eastward) thrust of the Potwar Sheet in post-Nummulitic times, with an obstructing barrier to its east and south-east, we can imagine a reaction causing fractures in the continuity of the advancing Salt Range front at the points J (Jalalpur) and P (Pind Savikka). The eastern end of the Jogi Tilla portion lagged behind, while its western end (at Pind Savikka) was dragged along to the south, giving this ridge a NE-SW trend. With the main part of the Range still pushing south, the Chambal portion broke off at both ends and we must assume some special obstruction in the region of Jalalpur to account for this portion turning round upon itself through 90 degrees. Or, as an alternative (and perhaps more plausible) explanation, the Chambal Ridge may be regarded as a displaced repetition of the main Range due to a strike fault running north-west from Jalalpur: the present course of the Kahan Kas roughly following the fault plane.

Whatever the true interpretation, it seems evident that these peculiar features of the Eastern Salt Range, and the erratic course of the River Jhelum to which I have previously drawn attention (1945, p. xxiii, Text-fig. 17), are in some way related to an obstruction offered to a south-eastward-moving nappe by a barrier situated to its east and south-east.

On 26 October, 1945 we motored from Jalalpur along the valley of the Kahan Kas up to a point east of Mangal Dev peak, and then walked along the shear zone of the Salt Marl, Cambrian and Tertiary to the high ground to the north, where there is a thick bed of white dolomite in the Saline Series (at first sight looking deceptively like a calcareous tufa). A sample taken from this dolomite (S. 92) has not yet been examined.

Ascending the section from this point in a general south-east direction we first crossed over to the junction of the top Gypsum and Dolomite with the Maroon Shales, incidentally collecting samples of some white to pink, slightly cherty banded dolomite (S. 93) from the top of the Saline Series just below the Maroon Shales; then over the Purple Sandstone on to its junction with the Neobolus Beds (here also marked by a thin but persistent basal pebble bed as in other parts of the Salt Range) and finally to the very interesting junction of the Neobolus Beds with the overlying Kamliak beds (Miocene) which form the highest ridge here.

The panoramic view reproduced in Plate 6 was made up from two photographs taken from the top of this ridge of Kamlials a couple of miles north of Jalalpur. The section here seen affords an excellent idea of this important Cambrian-Miocene unconformity, and of the topography in this eastern part of the Salt Range, with its imposing Siwalik dip-slopes and bold scarp faces.

(m) *Microfossils from Banded Dolomites below Maroon Shales north of Jalalpur*
(26 October.)

A few tiny fragments (sample S. 93) of the white and pink cherty Dolomite just mentioned were dissolved at my request by Mr. Lakhanpal in 4% HCl. After a number of lignified fibres and some small poorly preserved shreds of wood without any visible pitting (Text-figs. 32, 35) had been discovered, an elongated cell, apparently from the epidermis of a grass, was found (Text-fig. 34). Soon afterwards Mr. Lakhanpal prepared the well preserved fossil shown in Text-fig. 33, with the unmistakable characters of a grass epidermis. Even if we ignore the fibres and the badly preserved fragments of wood, the evidence of the grass cuticles is definite that the Dolomite cannot be of Cambrian or Precambrian age. (See also Plate 11 Photo 25).

3. MICROFOSSILS FROM THE SALINE SERIES (GENERAL SUMMARY).

In what I have said today, and in several papers published in recent years by myself and others, a body of evidence has been presented which shows that the Saline Series contains ample fossil material to enable us at least broadly to determine the age of the Series. This evidence relates to different kinds of rock-samples collected at many localities from Chittidil as far as Jalalpur, and taken from many different horizons, either exposed in outcrops or from mines and borings. Many of the samples were specially collected by Mr. Gee or other colleagues of the Cambrian school.

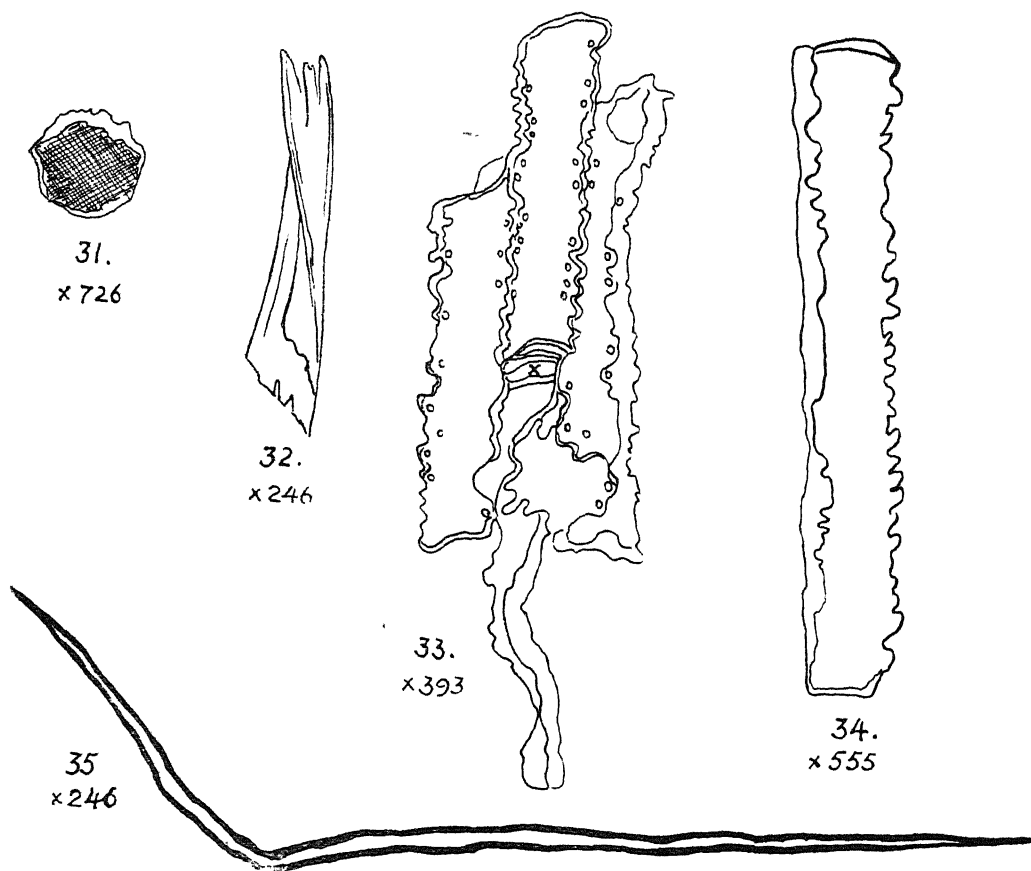
To this evidence Mr. Trivedi has added substantially by his comprehensive studies on Salt Range microfossils, which have now been completed and are being placed before you today. Here it will suffice to refer to his numerous illustrations of fossils classified under Rocksalt and Kallar, Dolomites and Oil Shales; and to his tabular summary of the fossils recovered from the various types of rocks.

The outstanding facts in this evidence are—

- (i) most of the sedimentary rocks of the Saline Series are rich in microfossils;

- (ii) the flora and fauna shows an essential similarity throughout (mainly woods of gymnosperms and angiosperms, plant cuticles and insect remains).

Although as a rule these fossils are not individually datable within narrow limits, the angiosperms are at least as young as Jurassic, and some of the insects must be Tertiary. We need not try to date the gymnosperms; this is an ancient group, going back to Devonian times, but even that period is far younger than the Lower Cambrian, which is the youngest age allowed to the Saline Series by Mr. Gee.



Text-figs. 31-35. Microfossils from a white and pink banded Dolomite below Maroon Shales north of Jalalpur (S. 93, coll. B. Sahni 26 Oct. 1945).

31 Spore-like body; 32 fragment of wood (pitting not visible); 33, 34 fragments of a grass cuticle; 35 a lignified fibre.

4. THE THEORY OF CONTAMINATIONS.

Are we to accept this fossil evidence on its face value or to reject it as unreliable because the field evidence, as interpreted by Mr. Gee and the Salt Range party of 1944, suggests a Cambrian or Precambrian age for the Saline Series?

The field data give so much play to the imagination that they have led to a degree of wavering of opinion scarcely justifying the confidence with which some geologists now uphold the Cambrian view. It is interesting to observe the reasons that led Sir Edwin Pascoe, until recently one of the chief supporters of the regional overthrust, to 'transfer his script' on the Saline Series (in his *Manual of the Geology of India*) from the Tertiary chapter to the Cambrian. It was not the discovery of any new data by himself but the grounds which had influenced Mr. Gee to revert to the Cambrian idea, added to the consideration that—

"the Manual is an official publication and should, as far as possible, present the views held by the Department as a whole" (Pascoe 1945 p. 207).

Let us now examine the theory of contaminations as advanced by the geologists of the Cambrian school.

(i) *Plasticity of Rocksalt and Salt Marl.*

The plasticity of Rocksalt and Salt Marl, and their capacity to intrude, over-ride, envelop and incorporate extraneous material, in fact to flow and behave in other ways much like a glacier, are admitted on all hands. But while making the fullest allowance for these facts one cannot afford to allow general statements on these well known phenomena to confuse the issue before us.

In the New Low Level Tunnel at Warchha Messrs. Gee and Coates showed me interesting sections where well bedded strata of Rocksalt and Kallar were seen to overlies sub-recent *débris*, and had apparently flowed for some considerable distance, no doubt during relatively recent times, so as to over-ride mixed scree material which had fallen near the mouth of the tunnel.

Similarly, in the Billianwala *nala* at Khewra, we saw some beds of sub-recent clays, conglomerates and sandstones which have a northerly dip like that of the Saline beds of the Salt Mine hill. Mr. Gee argued that percolating waters seeping through these incompetent sub-recent beds might easily carry fragments of modern organisms down into parts of the Saline Series lying at a lower level.

The possibility that the originally deposited Rocksalt and Kallar of the Saline Series may, in situations like those just described, become locally contaminated through cracks or solution holes, must be and has been freely admitted. What is difficult to accept is that such contamination has taken place on a microscopic scale, over such a wide area, and in such a refined manner as to have injected all the strata in the Khewra and Warchha mines, from which our samples were taken, with micro-remains of the same general types, without at the same time permitting the intrusion of the associated mineral matter. Has Mr. Gee or any one else made an attempt to explain the *modus operandi* of this extraordinary sort of selective contamination? Or, if foreign mineral matter has also taken part in the process, to demonstrate its existence in any of the spots of which photographs have been published?

You will have noticed that in my recent work I have avoided all reference to the microfossils in the Rocksalt and Marl, although this evidence is by no means easy to explain away. This I have done only in order to focus attention upon the fossils in the Dolomites and Oil Shales, to which Sir Cyril Fox (1945) and Sir Lewis Fermor (1946) have both declined, although expressly invited, to make any reference, while they are content to blame the Salt and Marl for their "incompetence".

(ii) *Dr. Lehner's theory of "Structural Intermixing" and "Assimilation" of Foreign Rocks in the Saline Series.*

Dr. Lehner has made a much more serious attempt to explain the way in which contaminations on a large scale may have taken place (1945 pp. 262-266).

He has made a list of geological periods from pre-Taichir to Recent during which a Cambrian or Precambrian Saline Series may have been exposed to contaminating influences. He describes what he calls "structural intermixing" of the Saline Series, coming "in intimate stratigraphical contact with a much younger formation, laid down on it along a perhaps very uneven erosion surface". And he goes on: "then it becomes easy to explain how structural processes could aid the complete assimilation of a new formation to the old".

Dr. Lehner's great experience as a tectonic geologist demands that his views should receive the most careful attention. But his statement, being couched only in general terms, cannot be expected to lead us very far.

Without any attempt to elucidate a single specific case he dismisses, as being of exotic origin, all the microfossils found in numerous localities and horizons through a thickness of 1,500 feet or more of Saline deposits, Dolomites and Oil Shales. With the additional evidence of fossils now before us, from Dolomites and Oil Shales at Chittidil and Ratta, from the Fatehpur Main gorge, from the Warchha and Khewra gorges and from core-samples at Khewra and lastly from the Dolomites at Jalalpur, the implication of Dr. Lehner's formula is that practically the entire Saline Series must have come under the influence of this "inter-mixing" during "structural processes", with the result that there has been a "complete assimilation" of a new formation into the Saline Series. Dr. Lehner does not specify the particular formation that has been thus invisibly assimilated, or state why only one formation was incorporated and not several of different ages. Obviously he is thinking, in preference, of a Tertiary formation because of the angiosperms and insects (which, by the way, he does not follow Mr. Gee and Dr. Lees in regarding as Cambrian). According to him (p. 262)

"it is also conceivable that microscopic organic matter might enter deep into the dolomites, being carried by moisture into microscopic pores and fissures. Even shales might be subject to similar contamination".

Here he parts company with his colleagues of the 1944 excursion who frankly admitted that they had no satisfactory explanation to offer for the occurrence of microfossils in the Dolomites and Oil Shales.

If an entire younger formation has been digested into the Saline Series, the microfossils once presumably contained in it must have become separated from the original mineral matrix in some mysterious way on which Dr. Lehner throws no light. One would like to know, too, what has happened to that original matrix, for we see no trace of it in the Dolomites and Oil Shales. Or is it suggested that the whole of the Tertiary matrix was *invisibly* mixed up with that of the Cambrian Saline Series during the "structural processes"? This would imply that while the *materials* of which the Saline Series is now composed are of at least dual nature (Cambrian+Tertiary) the present stratification of the entire series is a post-assimilation phenomenon! One might, to a limited extent, accept the theory of re-stratification in the case of Saline deposits, but would any geologist seriously think of extending that idea to the Dolomites and Oil Shales?

It will suffice to draw your attention to the single section at the head of the Khewra gorge (see Plates 4 and 5) and ask whether Dr. Lehner's theory

will apply. In this well known section the Maroon shales of the Purple Sandstone Series make a shattered junction with the Upper Gypsum-Dolomite stage of the Saline Series, which here includes, closely interbedded within a series of finely laminated sandy gypseous dolomites, not only a number of very thin bands of highly bituminous shales but also a contemporaneous lava flow, the Khewra Trap. The Trap here shows a well marked upper zone of vesicular lava indicating its extrusive origin and all the other beds show a perfectly conformable dip and strike. Is it at all possible to explain the lava here on the theory of inter-mixing and re-stratification?

(iii) *Mr. Pinfold's Objections to the Indigenous Nature of the Microfossils:*
Notes on fossil techniques.

A few words may now be devoted to Mr. Pinfold's objections to the indigenous nature of the microfossils (1945 p. 243). When prepared out of the rocks most of these organic remains, whether belonging to the Saline deposits or to the Dolomites and Oil Shales, are of a soft, pliable nature, unlike the mineralised remains which Mr. Pinfold has been accustomed to see in the Lower Chharat beds. When not heavily carbonised they frequently float in the rock solution. For these reasons he believes that they must be fragments of recent plants and animals accidentally introduced into the material.

Mr. Pinfold's fears are groundless. The pliable and stainable qualities of these microfossils merely indicate that the process through which they have passed has freed them of most of the mineral matter, leaving intact the organic residue which is frequently preserved in the rocks in considerable quantity. This residue may emerge as a pliable cutinised membrane or spore-coat, or (if not too drastically treated) as woody tissue, or even as thin cellulose walls.

That even fossils which to all appearance are fully mineralised often retain part of their original organic matter (although in a more or less altered state) is clear from the vivid stain which fossil cuticles, spores and woody shreds will readily take up.

I have frequently made use of this principle by staining with safranin or gentian violet thin sections of *silicified* plants from the Deccan Intertrappean Series (Early Tertiary), from the Rajmahal Series (Jurassic) and even from much older strata. When the clear siliceous matrix in a thin rock-slice is interspersed with specks of organic remains these are easily picked out by the stain, the matrix being left uncoloured.

Mr. Pinfold's objection that the stain is here merely caught in microscopic pores and cracks, and is not adsorbed as in sections of recent plants freshly cut and stained, also has no real basis, for I have recovered well formed spores and shreds of tissue from some of these Rajmahal and Deccan rocks (which are often packed with plant remains) by keeping little blocks undisturbed for a few days in HF; the fossils are found lying freely in the rock solution, and readily take up safranin. Of their organic nature there can be no possible doubt. Dr. Sitholey (1943) has similarly recovered numerous spores from Triassic rocks in the Salt Range which on the surface showed no sign of their presence.

Based upon the same principle is the technique of preparing "anthracograms" from plant remains which have become "oversilicified". In the process of petrification the silica may replace the organic matter to such an extent that thin sections will not show up the cell walls clearly differentiated from the matrix. But it is possible to show up even minute traces of the organic residuum in the cell walls by "combusting" them. A thin slice of the plant-bearing rock, or fossil wood, is kept immersed in a layer of liquid paraffin on a glass slide and the slide is heated over a gas flame, taking care that the paraffin does not catch fire. On examining the slice after this treatment the cell walls show up darker, owing to the slight traces of carbon now formed in them (see Kisser 1931).

On the same facts, again, depends the ingenious technique of "peel sections", first conceived by R. G. Koopmans (1928) but worked out and perfected by J. Walton and others (Walton 1928 p. 571 ; 1930). The mineral matrix of a coal-ball being readily soluble in dilute HCl, a smoothly cut surface showing plant-remains embedded in it can easily be etched with the acid, and now looks like a finished "process block". The plant tissues, being only partially mineralised, were not wholly destroyed by the acid, and stand out in relief. If we now pour over this etched surface a thick syrupy solution of a transparent substance that will on drying set into a thin, tough film e.g. celluloid dissolved in amyl acetate, or even gelatin, the film when carefully peeled off will carry away, embedded in its thickness, the projecting portions of the plant tissues, in other words a thin section of the tissues. Peel sections can be made in the same way from silicified plants, by using HF instead of HCl, and taking the usual precautions which the handling of HF demands.

As geologists generally are not acquainted with these facts, which are well known to palaeontologists (especially to palaeobotanists), I have answered Mr. Pinfold's objections in some detail. Also, while describing the microfossils, I have briefly indicated the techniques employed, most of which are very simple and easily varied according to the nature and chemical composition of the rock (see Harris 1926; Walton 1928; also Sternberg and Belding 1942). Some useful data concerning the nature of petrification will be found in two recent papers by Darrah (1941, 1941a) where further references to literature are also given.

Dr. Sitholey, Mr. Trivedi and Mr. Lakhanpal will briefly describe some of these methods when presenting their own papers before you. A brief note by Dr. S. Venkatachary, on the chemical treatment of rocks for preparing microfossils, and on the use of the micropipette in preparing single-spore mounts and other small fragments, is also appended. This was written with special reference to the carbonaceous shales within the Productus Limestone as exposed at the Waterfall section north of Warchha (unpublished thesis).

Note by Dr. S. Venkatachary.

Several methods regarding the chemical treatment of the material were tried and the one which gave excellent results is given below. This method is, in broad outlines, the same as that proposed by Harris for the investigation of fossil plants (New Phytologist, 1926, 25: 58-60).

The material was first washed with filtered distilled water to free it from any foreign spores, etc. sticking to it, and then oxidised with Schulze's macerating fluid, *i.e.*, a mixture of nitric acid and chlorate of potash. Very strong mixture was avoided as it might destroy the more delicate plant parts.

The residue was thoroughly washed with filtered distilled water to free it from the excess of acid and chlorate of potash, and a few cc. of ammoniacal solution added to dissolve away the oxidised material.

The residue was next thoroughly washed with filtered distilled water. Washing was done by adding water, allowing the mixture to stay for some time, then centrifuging, and decanting the fluid. Washing was carried on till no more of the water added turned brown.

The residue was placed in a wax-coated petri dish and a small quantity of hydrofluoric acid added. As dilute hydrofluoric acid was found to be quite satisfactory for desilicifying and demineralising, strong acid was used only in rare cases. The residue was very thoroughly washed, for any trace of hydrofluoric acid with its dissolved silica will cause the latter to be precipitated when an alkali is added.

After adding a few cc. of ammoniacal solution to the residue it was found to be very rich in organic matter, *i.e.*, spores, cuticles, tracheids, etc.

At the advice of Prof. B. Sahni the spores were stained with safranin *en masse* and thoroughly washed before they were examined under the microscope. Staining has not only made it easy to dis-

tinguish the organic matter from the inorganic but it has also brought out the details of the spore-coat which otherwise would have escaped our attention due to their great transparency. There is one more advantage in staining, that is, while one is examining the material under the microscope he can distinguish the fossil spores from any that might fall from the air on the slide, for the former are stained while the latter are not.

There are two good tests for the fossil spores prepared in the above manner: firstly, their flattened condition and, secondly, their stain. In the light of all these advantages it was found proper to stain all material before it is examined, i.e., before the atmospheric pollen has any access to contaminate.

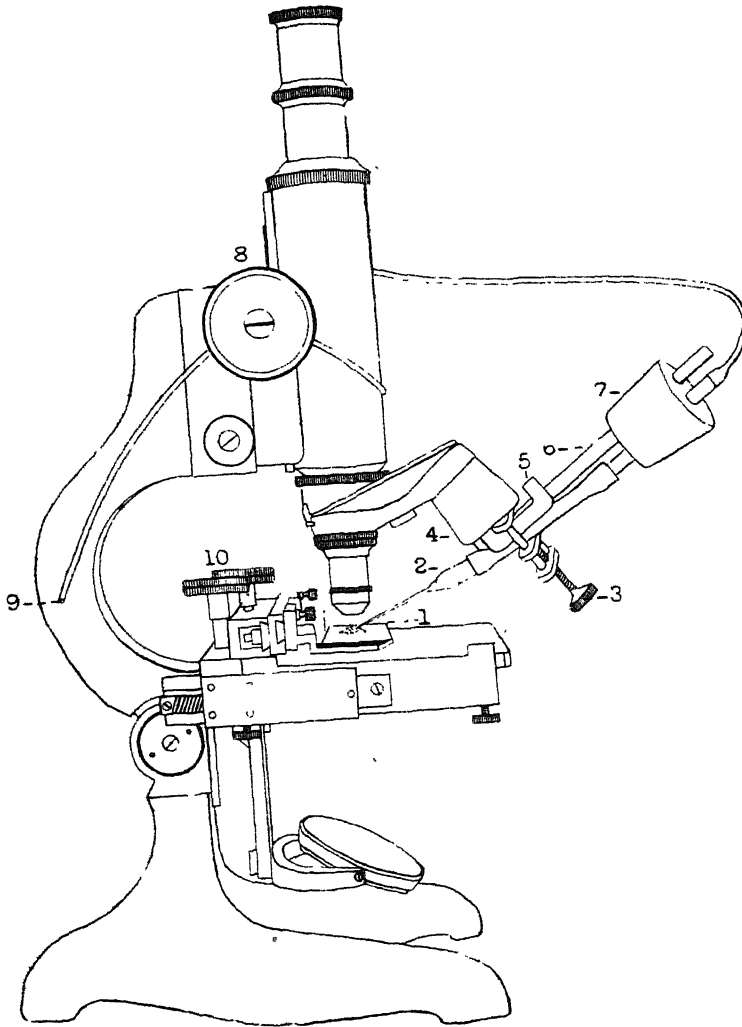
Material thus macerated showed a very large number of spores and other organic remains. Even the smallest quantity of material possible to be taken with a pipette was found to contain hundreds of spores. So the slides prepared by allowing a drop of water containing spores to dry and then mounted in balsam showed a very large number of spores. The chief difficulty with such slides is the inconvenience in locating the position of all the spores which constantly change their position and view-point as the balsam slowly hardens. In many cases balsam was found to be in a liquid state even one year after the slide was made. Consequently a large number of spores on the slide not only change their position but often some inorganic matter comes over an important specimen and thus obscures it.

In order to avoid all this trouble I decided to make single-spore mounts.

The importance and the advantages of single-spore mounts are too well known to need any mention. I tried various methods of picking up spores but I found most of the methods, including the one described by Erdtman ("Pollen Analysis", 1943: 40-42), to be not only inconvenient but also risky. So I have devised a spore-manipulator for making single-spore preparations. As its construction is clear from Text-fig. 36 no elaborate description is needed.

A drop of water containing the macerated material already stained with safranin is placed on a slide. When it is examined under the microscope fitted with the spore-manipulator the tip of the jet is also seen along with the material. When some interesting spore is spotted the tip of the rubber-tube is applied to the mouth to suck it up. The left hand works the coarse adjustment which is not only useful for focussing but is also needed for raising or lowering the jet; while the right hand is free to follow the spore by means of the mechanical stage. Once the spore has been sucked in, the jet is raised by means of the rough adjustment. By blowing air through the rubber tube a small droplet of water containing the spore is made to fall on a clean slide.

The slide containing the isolated spore is allowed to dry. A small droplet of Canada balsam or Euparal is placed over the spore by means of a very thin glass rod. Balsam of low viscosity is preferable for it dries up soon and will not allow spores to float and change their position and view-point. Slides prepared with thin balsam are better suited for observation under higher powers and oil immersion objectives. Cover glasses of a very small size or ordinary cover glasses cut into fours by means of a carborundum pencil make nice mounts. These small cover glasses by limiting the area to be searched minimise trouble and save time.



Text-fig. 36. Spore manipulator.

1. slide containing the macerated material; 2. micropipette; 3. pinch cock for keeping the jet in focus when different eye pieces are used; 4. three-holed rubber cork screwed into the socket of the high power objective; 5. J tube; 6. L tube; 7. two-holed rubber cork; 8. rough adjustment for raising the micropipette (for isolating the spore) when the desired spore is sucked in; 9. tip of the rubber tube which is applied to the mouth to suck up the spore; 10. pinions of the mechanical stage for following the spore.

The following note by Mr. Sud may also be found useful.

Note by Mr. C. P. Sud.

"A simple contrivance for macerating siliceous rocks containing organic remains."

In order to release the organic remains from siliceous rocks, the removal of arenaceous matrix involves treatment with hydrofluoric acid. The corrosive action of HF prevents the use of glass vessels. Coating the glass-ware with high melting-point paraffin wax and the use of copper and platinum ware have been suggested. Wax coated glass-ware cannot be thoroughly cleaned and if even a small area is left uncoated, HF is able to dissolve out the glass leaving walls of wax which collapse on the application of the slightest pressure. Copper consumes some of the acid in forming a layer of fluoride. The high cost of platinum prohibits its use for daily routine work.

The following contraption is suggested :—

The reaction vessel consists of a bicycle rubber tube (about 3 cm. in diam. and of any convenient length), one end of which is closed by a rubber cork to provide a water-tight base for the tube. The distal end of the tube is cut so as to leave a projecting flap 1 cm. in height, which can be bent back to close the tube.

The chief uses of this device are its cheapness, complete resistivity to HF of all strengths, the ease with which everything can be washed and the possibility of completing the reaction without involving an exposure to the atmosphere. Out of one discarded bicycle tube a dozen units can easily be made.

The tube is thoroughly washed and a weighed amount of rock is placed in it. The requisite amount of HF (precalculated) is also filtered in and the projecting flap turned over and clamped. When the disintegration is complete the flap is cut off and the suspension received in a fairly concentrated filtered solution of boric acid which will prevent the action of any excess of HF upon the glass container. Successive washings with filtered distilled water will make the material ready for examination.

During a visit to Britain in the summer of 1946 at the Royal Society's Scientific Conference I took the opportunity of demonstrating the microfossil method, as applied to the Salt Range problem, before geological gatherings in Edinburgh and London, when informal discussions were held. At Edinburgh facilities were kindly provided by Dr. Campbell at the Grant Institute of Geology (July 2 and 3). In London Mr. W. N. Edwards was good enough to allow the use of a room in the Department of Geology at the Natural History Museum, South Kensington (July 9 to 24). On both occasions samples of Dolomites and Oil Shales from the Salt Range were treated and fragments of woody tissue were recovered from them. Some of the microfossils already prepared, and figured in this paper or in others published previously, were exhibited.

I am grateful for the opportunity which these meetings afforded me to meet distinguished colleagues and discuss with them the possibilities of em-

ploying these methods to stratigraphical and structural problems. It is my hope, in the not distant future, to visit some of the "clean cut thrusts" in Switzerland and elsewhere in order to see whether it is possible to confirm these well established facts with the aid of the microfossil technique. This will, of course, depend upon whether the rocks involved in these thrusts are amenable to this kind of treatment and whether any microfossils recovered from them can prove the relative ages of the rocks above and below the tectonic plane.

5. MICRO-ANALYSIS OF TEST SAMPLES OF KNOWN AGE (AS A CHECK AGAINST THE CONTAMINATION THEORY).

At the Poona meeting it was suggested that, as a check against the contamination theory, some test samples of rocks of known geological age should be examined. Before we had met at Poona a number of such data were already available, and further samples have since been examined. These tests have uniformly given consistent results: there have been no puzzling anomalies. I may add that all this work has been done by students working in the same laboratory at Lucknow.

We have now, for some years, been familiar with the general character of Lower Gondwana microfloras, which mainly consist of microspores, winged and unwinged, mixed with some cuticles and a few types of woody tissues. Some of these spore types were discovered by Miss C. Virkki (now Mrs. K. Jacob) in 1937 in the Bacchus Marsh Tillite from Victoria, Australia. She next examined rock samples from four different horizons in the Lower Gondwana shales at Kathwai, in the Salt Range, and prepared microfossils which revealed a flora of the same general character (1946). In the carbonaceous shales within the basal part of the Productus Limestone at the Waterfall section north of Warchha, she again found the same types of spores, with no strange admixture of fossils such as might be expected on the theory of contamination. Similar results were obtained by her also from Lower Gondwana shales in the Daltongunj Coalfield; and Dr. K. R. Mehta, working on shales from the South Rewa Gondwana Basin, has since recovered much the same type of microflora, including several new [types of cuticles (1945).

Recently Dr. S. Venkatachary has fully confirmed Miss Virkki's results by his work on the Warchha shales (1945).

Miss Virkki (1946) examined a sample of *Glossopteris*-bearing shale from the Newcastle Series (Lower Gondwana) at Newcastle, New South Wales and discovered in it mainly spores of the *Pityosporites* type which are now known to occur commonly in the Lower Gondwanas.

Samples of the Dwyka tillite from near Johannesburg, S. Africa, were recently examined by Mr. D. D. Pant (1942, 1943) who again discovered the same types of spore forms as those found previously in the Bacchus Marsh tillite, as well as some new forms. This is a significant confirmation that the two tillites, separated by a distance of several thousand miles, both belong to the Lower Gondwanas. We are not here concerned with any closer correlation but with the fact that the two rocks showed an essentially similar flora, with no incompatible exotics.

Of Indian rocks much older than the Gondwanas only two horizons have yet been examined but the results, so far as they go, are again consistent with what was expected. A sample of the Purple Sandstone in the Khewra gorge, just north of Anderson's locality, has been very carefully examined by J. Hsü (1946) but yielded no organic remains of any kind, although as many as 82 preparations were made. This fact is consistent with the idea that the Purple Sandstone is a very ancient deposit, dating back to a time when no vascular plants with woody tissues, cuticles or cutinised spores existed. Similarly Dr. Venkatachary has found only negative results from an examination of the Lower Tal Beds in the Himalayas in spite of repeated efforts to bring out organic remains. It must, of course, be admitted that this negative evidence from a few samples does not necessarily mean that the rocks are unfossiliferous, or indicate beyond doubt that they are of very ancient dates. But, so far as they go, the results are consistent from our present point of view, for they showed no contaminations of any kind.

Hsü (1946 a, 1946 b) has also examined with great care, in the same laboratory at Lucknow, some material of Devonian plant-bearing rocks from several localities in South-Western China. Numerous microfossils, mainly spores, were prepared and figured (in a paper not yet published), but not a single fragment was discovered, such as an angiosperm wood or cuticle, which could be suspected as a contamination.

Lastly, I may mention that core-samples from the Tertiary oil-bearing system in Assam have also been examined at Lucknow, on behalf of the Burma Oil Company¹. I have Mr. Coates's permission to publish the fact that in a general way it is possible to correlate the samples and confirm their reference to the different horizons, Barail, Surma, Tipam, etc., solely on the basis of the

¹The laboratory work was carried out initially by Drs. R. V. Sitholey and G. S. Puri, and latterly by Mr. B. S. Trivedi, Mr. R. N. Lakhanpal and Dr. S. Venkatachary. The full results will be published elsewhere.

microfossils. Our experience here is thus parallel to that of palaeobotanists in many other countries where Carboniferous and Permian coal seams and their associated strata, as well as Pleistocene and younger peats, have for many years been correlated on their contained microfossils. One cannot, indeed, claim that in this type of work some small amount of contamination from laboratory sources cannot take place; but because the microfossils occur in thousands, and because any modern contaminations must be a common factor throughout (e.g. occasional scales of lepidopteran wings, or modern mites which occur in the atmosphere), their vitiating effect upon the general results can be safely eliminated.

6. OTHER SOURCES OF EVIDENCE.

It is a pity that, except for what little we know of the distribution of heavy minerals in the Saline Series, which on the whole supports a Tertiary age (Evans and Majeed 1935), our other lines of evidence have so far borne no fruit. The samples of Khewra Trap sent out to experts for radio-active analysis have not yet been reported upon. As regards the idea of comparing the magnetic orientation of rocks above and below the Saline Series—Palaeozoic junction, no single section was found where the rocks both immediately above and immediately below the junction were sufficiently compact to be suitable for a magnetic test.

7. THE INTERPRETATION OF STRATIGRAPHICAL CONTACTS IN THE FIELD: EXPERIENCE IN OTHER PARTS OF THE WORLD.

Relying upon his own (revised) interpretation of the field relations of the Saline Series, Mr. Gee wrote last year (1945 p. 306) that if the fossil evidence should prove a post-Purple Sandstone age then it would be

“necessary to modify our views regarding the essential characteristics of normal sedimentary and tectonic contacts”.

In his view (1945 p. 327) a regional thrust of the type suggested by the fossil evidence must show externally visible signs of disturbance *in all sections* where the junction is clearly exposed. He would not be satisfied if proofs of disturbance are seen even in a majority of these sections. He writes :

“Although there may be numerous instances of a tectonic junction at the top of the Saline Series, if this is not universal throughout the Salt Range then all such field-evidence favouring a post-Cambrian age for the series disappears”.

Here, I have little doubt, Mr. Gee is expecting too much of the field evidence, which has so often proved a treacherous guide. It has failed us repeatedly in the Salt Range, as is evident from the number of times geologists have changed their views concerning the age of the Saline Series, with essentially the same facts before them. In the Deccan Trap problem, too, the fossil evidence for a Tertiary age was clear and unmistakable from the start, well over a century ago. Nevertheless, experienced geologists from W. T. Blanford down to the present day have vainly tried to overthrow it by stressing the significance of field data which could scarcely stand the test of scrutiny. Mr. S. R. Narayan Rao (1941) has shown the futility of these attempts by special reference to the well known sections near Surat and Broach, upon which Blanford had relied in the way that Mr. Gee now relies upon his key sections in the Dhodha Wahan (see also First Symposium p. xx).

Where fossil control is not readily available, the field geologist has perforce to rely upon his own interpretation of stratigraphical contacts. In this process imagination and the personal factor may play a large part. As this matter is of crucial importance to our discussion and involves principles of wide application, it would not be out of place to consider parallel cases in other parts of the world where great overthrusts, of which the existence was long disputed because the stratification appeared to be undisturbed, have been demonstrated by eminent geologists and are now universally accepted.

I may be permitted to place briefly before you such information as I have been able to gather, with reference to the general question involved.

Professor J. S. Lee of Chungking, whose work on tectonic structures in China is well known, read the papers presented at our Poona meeting and wrote to me (18 May, 1946) as follows:

"Have you ever.....tried to explore the possibility of securing some tectonic evidence by working out the microscopic structures of the Saline Series as seen at Khewra and Warchha? The suspected thrusts must have left some traces in the beds involved even though they appear to be innocent megascopically. Here in this country we often gain some light as to the tectonic relation of rock-masses by closely following minute joints, cleavages etc. developed in the masses and by detecting the optical orientation of the individual crystal grains. At least they ought to reveal the state of stress they have been subjected to".

Here is a fertile suggestion for geologists in this country. Let them investigate the Salt Range problem from this fresh viewpoint. If the Circuit House section at Warchha and the section at Chhabil (Plate 2 Photos C,D) show an undisturbed sedimentary contact, let a comparison be made, on the lines suggested by Professor Lee, with the well known section at the head of the

Khewra gorge, or with the section a mile west of Jalalpur, both of which are obviously disturbed, or with other similarly shattered junctions in the Salt Range of which the presence is admitted by Mr. Gee. But whether these comparisons are carried out or not, we at least know on the authority of Professor Lee that *in China there exist indisputable tectonic contacts where there is no external evidence of the movements involved.*

To Mr. J. B. Auden I am indebted for equally interesting information concerning the external appearance of known thrust planes in this country. Writing on the 28th November, 1945 in reply to an enquiry, he said :

“With regard to the external signs of disturbance along thrust planes, it must be admitted that these evidently bear no relation to the presumed magnitude of thrust displacement. There are outliers of phyllites and schists close to Dehra Dun and south-east of the Ganges which rest variously on Nummulitic, Tal limestone and Tal quartzite, without folding or mylonisation, in spite of a probable disturbance of translation of 40 miles or more. On the other hand, I have found mylonised quartzite and strong folding in the great Garhwal Window, where the Garhwal quartzites are highly disturbed below the over-riding schists of the Dudatoli-Almora zone. As Wadia has told you, there is in some parts of the Alps almost a complete lack of disturbance at the contacts; while on the other hand major thrusts in the Jungfrau massif have caused extensive imbrication and some mylonisation in a manner resembling the North-West Highlands of Scotland. These different behaviours are presumably related to the magnitude of load carried by the overthrust mass (or overlying the under-thrust mass) and on such factors as the coefficient of friction along the planes of movement”.

Mr. Auden has since paid a visit to the Salt Range and will no doubt have arrived at his own conclusion on the specific question before us. Some time earlier Mr. Wadia had drawn my attention to instances in the Alps where in one locality older strata overlie much younger ones with obvious mylonisation of the contiguous rocks, while in another section, not far off, the same sequence forms an apparently undisturbed contact. He has since placed in my hands the very lucid account of the “Structure of the Alps” by Professor L. W. Collet (1927) where that author speaks of invisible thrusts of the “clean cut” type; and during a recent conference in London I had the good fortune to meet Professor Maurice Lugeon from whom I had first-hand confirmation of the fact that *outward evidence of disturbance is by no means an essential feature of thrust planes.*

Professor T. G. Halle, writing to me on February 19, 1946, said :

“Is it not a fact that in the Alps great overthrusts are known to occur in series where the stratification seemed to be normal? I have talked to some Swedish geologists who have a wide field experience from our Caledonian mountain range. They say that quite undoubted overthrusts on a large scale sometimes cannot be located even in a well-exposed section, the succession of strata appearing quite undisturbed. One of them mentioned a case from Scotland where the overthrust plane may be found running through a single handpiece of the rock, the contact zone being of not much more than the thickness of a leaf and separating apparently undisturbed layers”.

[*Postscript added 30 January, 1947.* The printing has been so long delayed that it is now possible to insert a reference to an interesting section on the Pidh road, about 5 miles from Khewra, which I photographed on 28th November 1946 (see Plate 7) during a recent excursion with Messrs. E. R. Gee, J. B. Auden and my brother Dr. M. R. Sahni. Here a clean wedge of the Talchir Boulder Bed (Upper Carboniferous) has apparently been thrust almost horizontally into regularly stratified Salt Pseudomorph Shales (Cambrian) *without causing any appreciable disturbance in the bedding of the shales above and below.* Although the plane of contact is clearly a tectonic one, it has all the appearance of a normal sedimentary junction and might have been interpreted as such, were it not for the fact that the upper limb of the V-shaped contact plane is also clearly exposed. On my return from the excursion I came to know from my colleague Mr. S. R. Narayan Rao, that he had already examined and photographed that section in October, 1946. He proposes to discuss it fully elsewhere but I wish to thank him for allowing me to make a brief reference to it here—*B. Sahni.*]

8. FIELD EVIDENCE NOT A SAFE GUIDE WHEN IT CONFLICTS
WITH FOSSIL EVIDENCE.

Enough has been said to show that the field criteria upon which reliance is placed by the geologists of the Cambrian school are not safe criteria. The Salt Range question which has so long baffled us is no longer a problem of local significance: we must learn to judge it by standards based upon wider experience. And where the field evidence appears to conflict with the internal evidence of the fossils we must be prepared to agree that there may be something wrong with our reading of the field evidence.

In November, 1944 the Salt Range party led by Mr. Gee, when giving a unanimous verdict in favour of the Cambrian view, wrote in a joint letter to *Nature*:

"our conclusions were arrived at despite certain difficulties, such as the occurrence of minute plant fragments of post-Cambrian age in the dolomites and oil shales, for which at present we have no clear explanation to offer".

The only clear explanation is that the fossils are strictly in situ and contemporaneous with the rocks, which therefore cannot be so old as Cambrian.

Quite recently an alternative explanation has been offered by Mr. Gee. *The suggestion is that the angiosperms, gymnosperms and insects of the Saline Series may represent a highly evolved Cambrian or Precambrian flora and fauna!* In other words, it is suggested that these plants and animals made their appearance in the

Salt Range area several hundred million years earlier than they did anywhere else in the world. One would scarcely have believed that such an idea would be seriously put forward by any geologist today. But if Mr. Gee still believes that the microfossils are "contaminations" of recent origin, then he will not need to repudiate the principles of palaeontology by giving to these highly evolved groups an age so ancient as Cambrian or Precambrian.

The work of Mr. Gee and of some of his colleagues at the Geological Survey of India has shown how, in the hands of an able geologist, essentially the same field data can be interpreted in favour of either the Cambrian view or the Tertiary. This fact raises the hope that they will again be able to reconcile their field evidence with the unflinching evidence of the microfossils.

Here there is no compromise possible: of the tectonic nature of the Saline Series—Palaeozoic junction there can be no doubt whatever. Now we know that the fossil evidence does no violence to this interpretation of the field evidence as judged by accepted geological standards.

9. CONCLUSION

Apart from proving, in my opinion beyond a shadow of doubt, a Tertiary age for the Saline Series, the present discussion has brought to the fore the following facts of general significance:

(i) Between the testimony of the rocks and the testimony of the fossils there can be no real conflict. When the two do not seem to agree it is the direct evidence of the fossils that is to be relied upon: palaeontology is a surer foundation for stratigraphy than field evidence.

(ii) However innocent of fossils a sedimentary rock may appear to be, even in thin sections under the microscope, it may yet be quite rich in microfossils. Here modern technique comes to our aid. Only the most ancient sediments, or those badly metamorphosed, are totally unfossiliferous.

(iii) When even traces of megafossils are to be seen on the surface, the rock-matrix, suitably treated, is sure to reveal microfossils, and these will generally give a much richer and more representative picture of the flora and fauna than the megafossils.

(iv) In some respects microfossils are more useful for stratigraphical work than megafossils.

(a) Being widely disseminated in the rocks, they can usually be found even if tiny rock-samples are examined,

(b) For each true species of large plants or animals there must be several artificial species of microfossils, *e.g.*, in a vascular plant the spores, the cuticle and the woody tissues; and in an insect the body cuticle, the legs, the antennae or other parts, each of which can have stratigraphical value. Even if its exact affiliations are unknown, so long as we know a microfossil specifically, it will have the same age value as the complete body of the plant or animal (Sahni 1939).

(v) For the same reasons microfossils can also be of great use in structural geology, *e.g.*, in detecting or confirming the presence of faults, thrusts, unconformities and inversion of strata, whether of a purely local or of a regional character.

(vi) But the limitations of this kind of work must also be recognised. Before any wide use can be made of microfossils in stratigraphical and structural geology a mass of basic data on the microstructure of fossil remains has to be collected, so that isolated microfossils can be more easily affiliated and more closely dated than they can be at present. In particular, there is need of more data on the microscopic features of chitinous animal remains on the lines of the work already done on the spores and cuticles of plants. The Salt Range problem, it must be admitted, is an exceptionally favourable one for attack by the microfossil technique, because of the vast difference in age between the Cambrian and the Tertiary.

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11. EXPLANATION OF PLATES 8-11.

Plate 8.

(All the photographs are from untouched negatives).

Photos. 1-4. *Fossils from Rocksalt and Kallar.*

1. Chitinous membrane with numerous barbed setae attached in bulbous sockets. Specimen "Sahni No. 1", Slide 2. From Pharwala seam, Mayo Mine, Khewra. $\times 83$.
2. Part of the same specimen, to show details. $\times 900$.
3. *Chironomus primitivus* Mani. From a band of kallar in a tunnel in the Salt Mine at Warchha. Specimen "Sahni No. 1" Slide 53. $\times 61$.
4. Cuticle of one of the Gramineae, showing three characteristic stomata among elongated sinuous-walled epidermal cells. From Pharwala seam, Mayo Mine, Khewra. Specimen "Sahni No. 1" Slide No. 1. $\times 307$.

Photos. 5-8. *Fossils from Oil Shales.*

5. Chitinous membrane with numerous smooth and sharply pointed bristles projecting from sockets. From Oil Shale, interbedded with finely laminated sandy gypseous Dolomites of the Upper Gypsum Dolomite Stage, Saline Series, Khewra gorge (Anderson's locality). Specimen No. S. 81, coll. E. R. Gee and B. Sahni, 23 October, 1945. (Compare Text-figs. 28, 29). $\times 900$.
6. Chitinous membrane with sockets—and a few pointed setae attached. Specimen No. S. 81. $\times 700$.
7. Piece of wood with medullary ray. Fatehpur Maira gorge. Specimen No. S. 57. $\times 180$.
8. Part of the above specimen, to show detail. $\times 333$.

Plate 9.

(All the photographs are from untouched negatives).

Photos. 9-13. *Woody microfossils embedded in situ.*

9. Section of Oil Shale vertical to the planes of bedding, showing numerous small woody pieces embedded in the rock *in situ* (see Text-fig. 8a). Fatehpur Maira gorge. Specimen S. 57. Coll. E. R. Gee and B. Sahni, 17th October, 1945. $\times 57$.

The Age of the Saline Series in the Salt Range (Second Symposium).

10. Two shreds of wood from the above slide, magnified. The piece on the right-hand side represents a tangential section of the wood, and shows several well preserved medullary rays cut transversely (see Text-fig. 8). $\times 670$.
11. Section of Oil Shale from Warchha, cut parallel to the planes of bedding, to show a small embedded piece of carbonised wood. From an outcrop of the Oil Shale Group near the confluence of the Jansukh and Jarhanwala streams in the Warchha gorge. Specimen No S.R.E. 38. Slide No. 15. $\times 50$.
12. The above specimen of wood. $\times 207$.
13. The same specimen further magnified to show a row of small simple pits. $\times 750$.

Plate 10.

(All the photographs are from untouched negatives).

Photos. 14-17. *Microfossils from dolomite.*

14. Part of an insect's leg (see Mani 1946 Text-figs. 6 and 8). From an outcrop of dolomite in the Oil Shale Group near the confluence of the Jarhanwala and Jansukh streams, Warchha gorge. Specimen S. 21/1, coll. B. Sahni, 13 October, 1943. Slide 47. $\times 335$.
15. Stellate hair, no doubt of an angiospermous plant. Specimen S. 21/1, Slide 48. $\times 260$.
16. Grass cuticle with several stomata and sinuous-walled epidermal cells. Specimen S. 21/1, Slide 46. $\times 500$.
17. Septate fungal hypha. Specimen S. 21/1, Slide 10. $\times 720$.

Photo. 18. *Microfossils from Talchir Boulder Bed.*

Coniferous tracheid with bordered pits and two medullary rays, in radial view. From a calcareous shaly horizon within the Boulder Bed, east of Chittidil Rest House (see Plate, 1, Photo. A, and Text-fig. 25). Specimen S. 65A. coll. B. Sahni, 19th October, 1945. $\times 385$.

Plate 11.

(All the photographs are from untouched negatives).

Photos. 19-21. Woody tissues embedded *in situ* in Fatehpur Maira Oil Shale (S. 57).

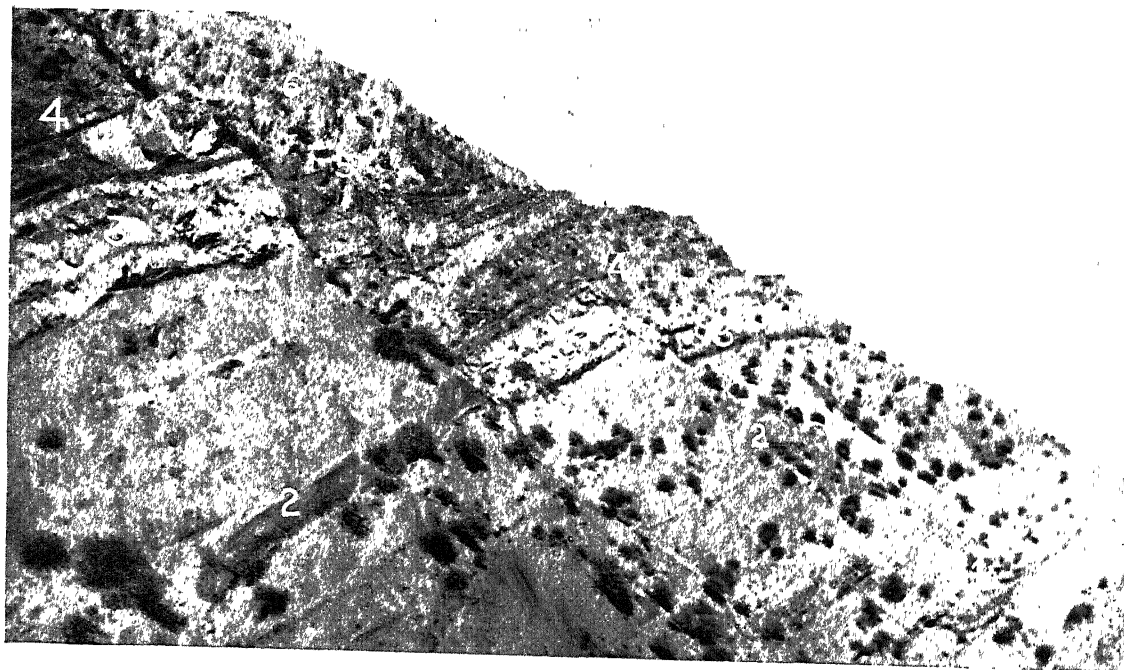
19. Section of Oil Shale cut vertically to the bedding planes. *The strip running horizontally across the middle is nearly all composed of fragments of wood, probably the result of breaking up of an originally single piece.* $\times 75$.
20. Part of the same section, further enlarged. The dark patches are bituminous matter. $\times 115$.
21. Part of the same section, showing a continuous piece of wood (probably of a dicotyledon) with a dozen fusiform medullary rays. $\times 146$.

Photo. 22. Fragment of a cylindrical chitinous body of unknown nature. Compare Text-figs. 6, 7. $\times 146$.

Photo. 23. A cylindrical chitinous body with a thick smooth sheath and a reticulately raked core. On the right is a piece of wood. Prepared by Mr. Trivedi from a sample of Rocksalt and Marl from a tunnel in the Salt Mine, Warchha. Sahni No. 1 Slide 54. $\times 146$.

Photo. 24. A fossil almost identical with that seen in Photo. 23. Prepared by Mr. Trivedi from a Tertiary shale in Assam. Sample P. A. 19, from Baragolai Well 1. Barails—Group 8. Depth 3,338 to 3,344 ft. Slide No. 3. $\times 146$.

Photo. 25. Cuticle of a grass. From banded pink and white Dolomite below Maroon Shales north of Jalalpur. (S. 93, coll. B. Sahni, 26 October 1945). $\times 240$.



A

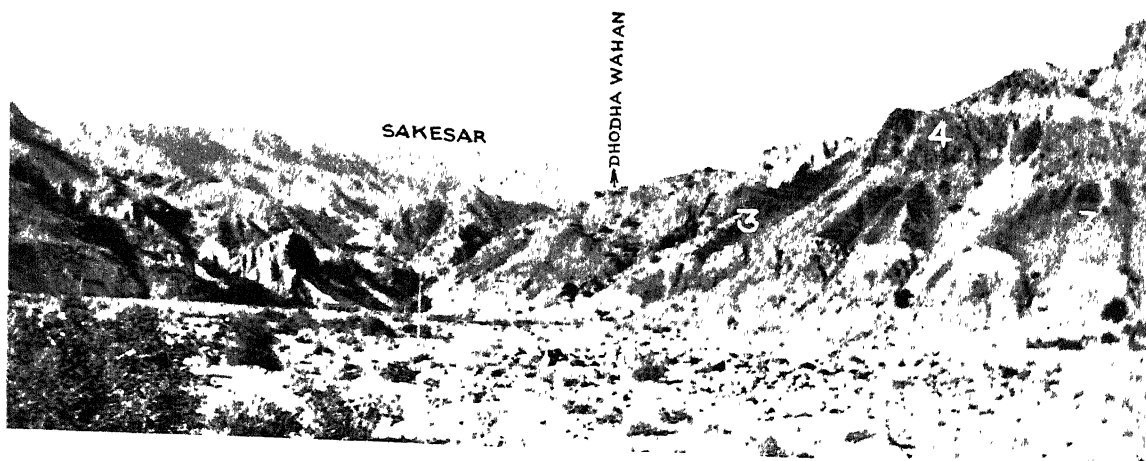
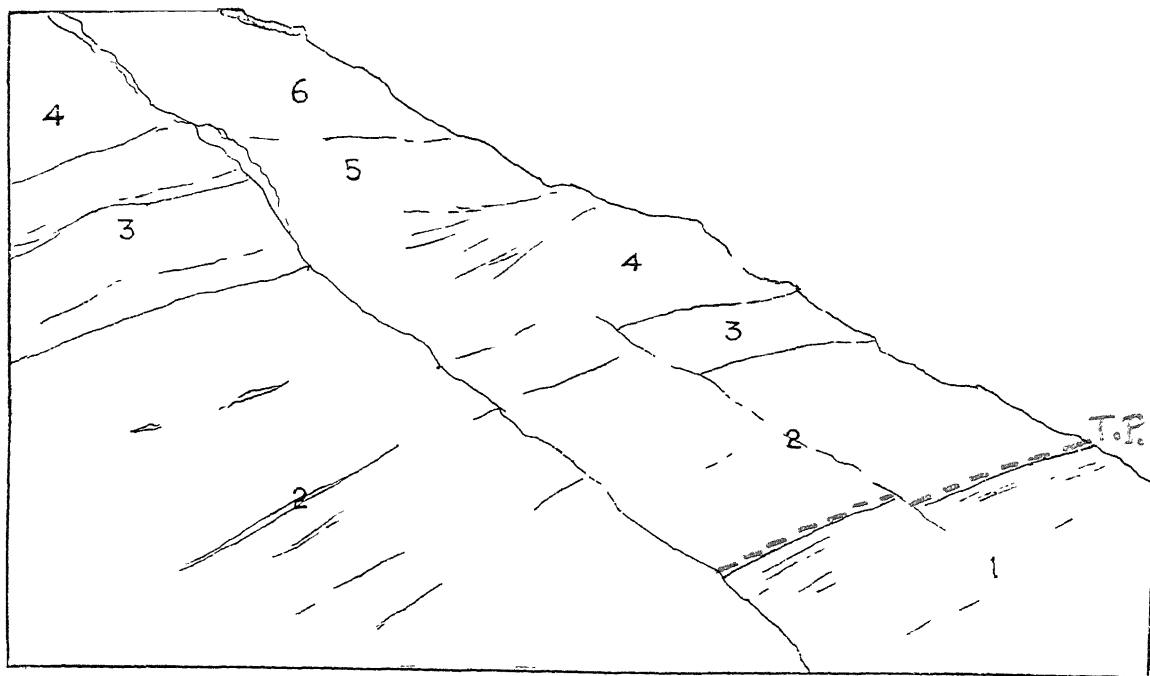


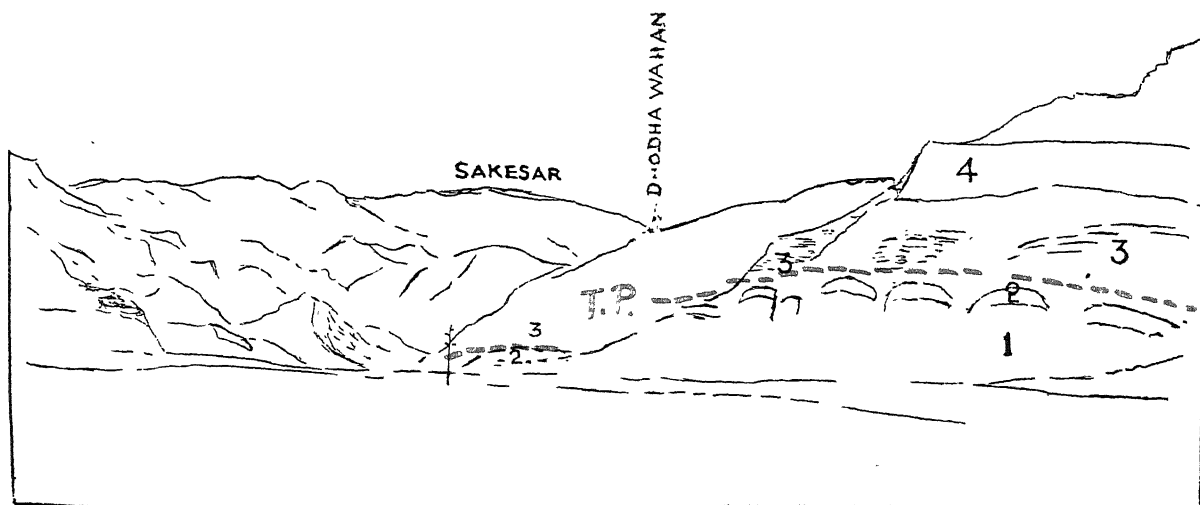
Photo: Sahni.

B



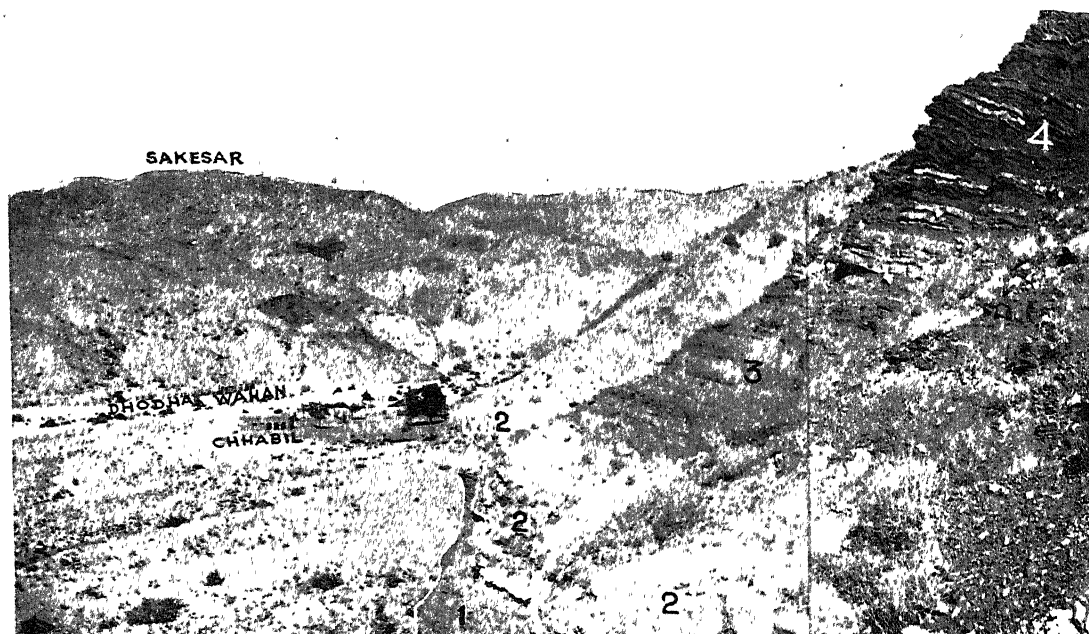
A. Section in the Dhodha Wahan east of Chittidil Rest House, south of Sakesar; Saline Series overthrust by the Carboniferous (B. S. Photo., 19 Oct. 1945).

1. Saline Series. 2. Talchir Boulder Bed. 3. Conularia Beds. 4. Speckled Sandstone. 5. Lavender Clay. 6. Productus Limestone. T. P. Thrust plane.



B. Debouchment of the Dhodha Wahan at Chhabil, showing the Upper Gypsum-Dolomite stage of the Saline Series, overthrust by the Cambrian (B. S. Photo., 17 Oct. 1945).

1. Red Marl. 2. Top Gypsum-Dolomite. 3. Maroon Shales and Flags. 4. Purple Sandstone. T. P. Thrust plane.

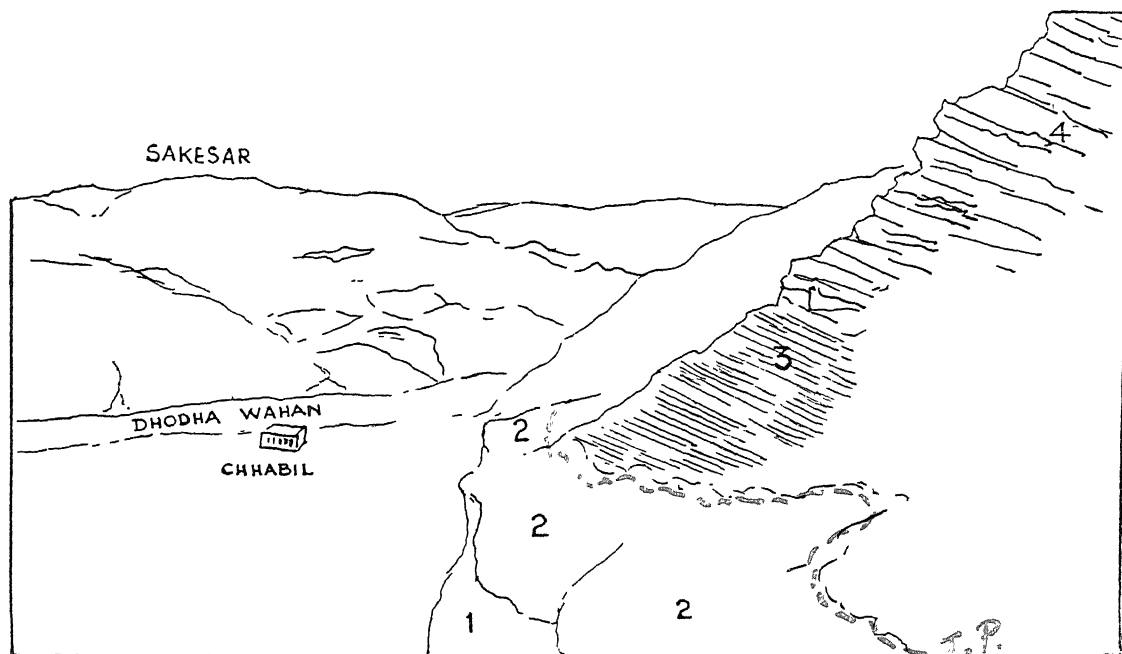


D



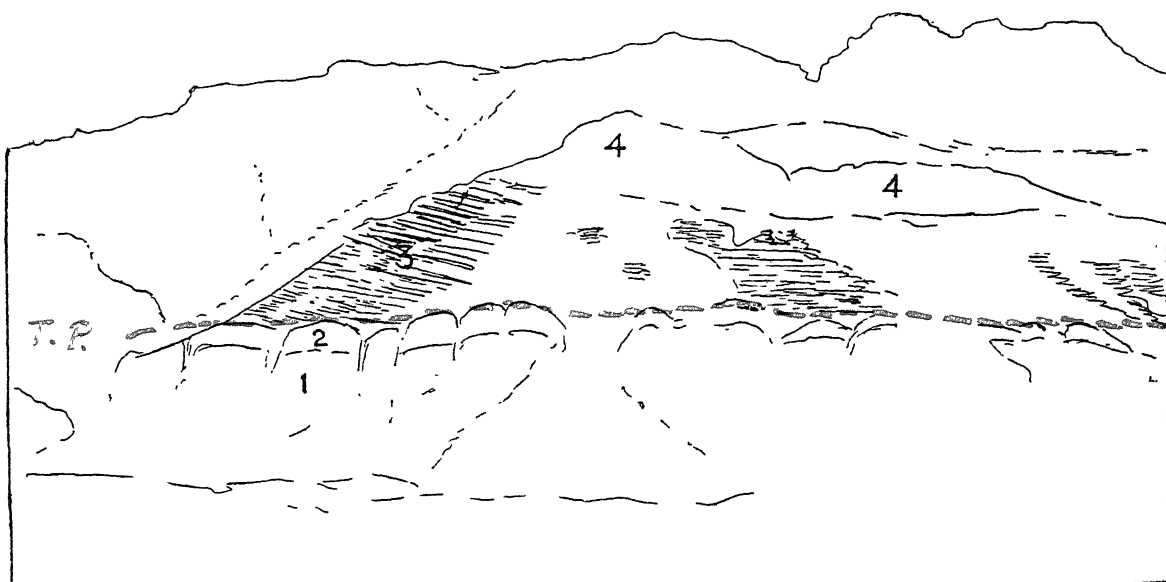
Photo: Sahni.

C



D. Part of the same section as in Photo. C; view looking north, from the level of the thrust junction (B. S. Photo., 29 Nov. 1946).

1. Red Marl. 2. Top Gypsum-Dolomite. 3-4. Maroon Shales and Flags. T. P. Thrust plane.



C. The Chhabil section showing the Saline Series—Maroon Shales thrust, viewed from the West (B. S. Photo., 17 Oct. 1945).

1. Red Marl. 2. Top Gypsum-Dolomite. 3. Maroon Shales and Flags. 4. Purple Sandstone. T. P. Thrust plane.

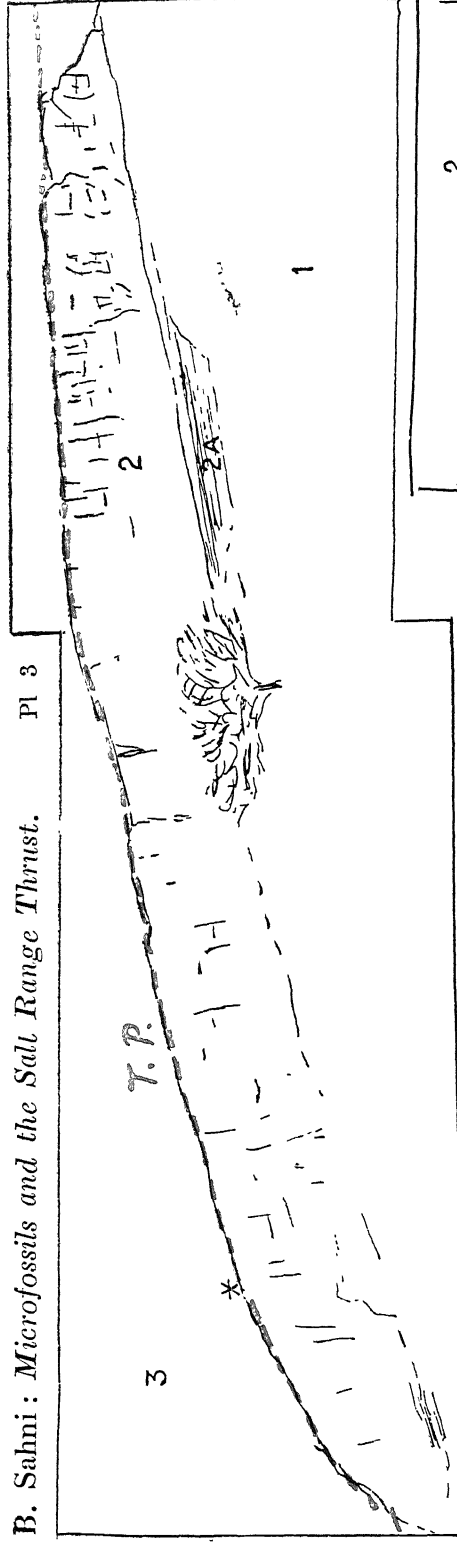


E



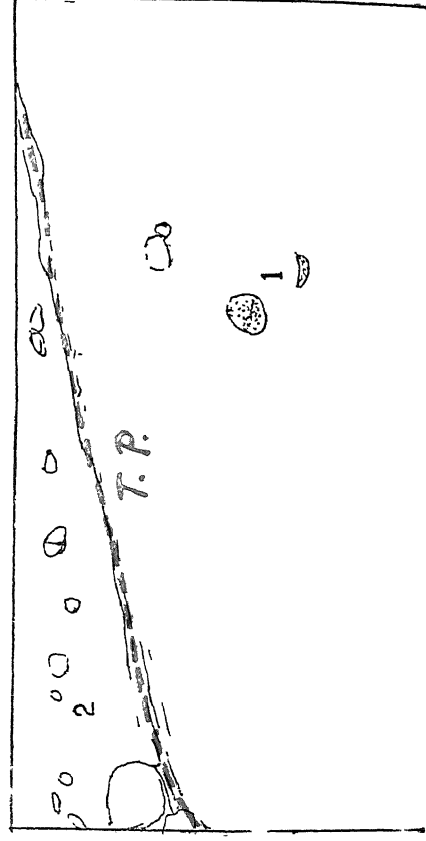
F

Photo : Sahni.



E. Section near Ratta, N. E. of Chittidil, showing the Talchir Boulder Bed thrust over the Top Dolomite of the Saline Series. (B. S. Photo., 1 Dec. 1946).

1. Salt Marl. 2. Massive Dolomite with Lower Zone (2-a) of Cherty Dolomite and Oil Shales. 3. Talchir Boulder Bed. T. P. Thrust plane. * See Photo. F.



F. Exposed upper surface of Dolomite at * in Photo. E, showing two Talchir boulders half embedded in the Dolomite, to the left and bottom of the numeral "1". (B. S. Photo., 1 Dec. 1946).

1. Dolomite. 2. T. B. Bed, with one split boulder. T. P. Thrust plane.



G. Lower part of the section E, continued to the left across the ravine (B. S. Photo., 1 Dec. 1946).

1. Lower Zone of Cherty Dolomite, with Oil Shales. 2. Massive Dolomite.

B. Sahni : Microfossils and the Salt Range Thrust.

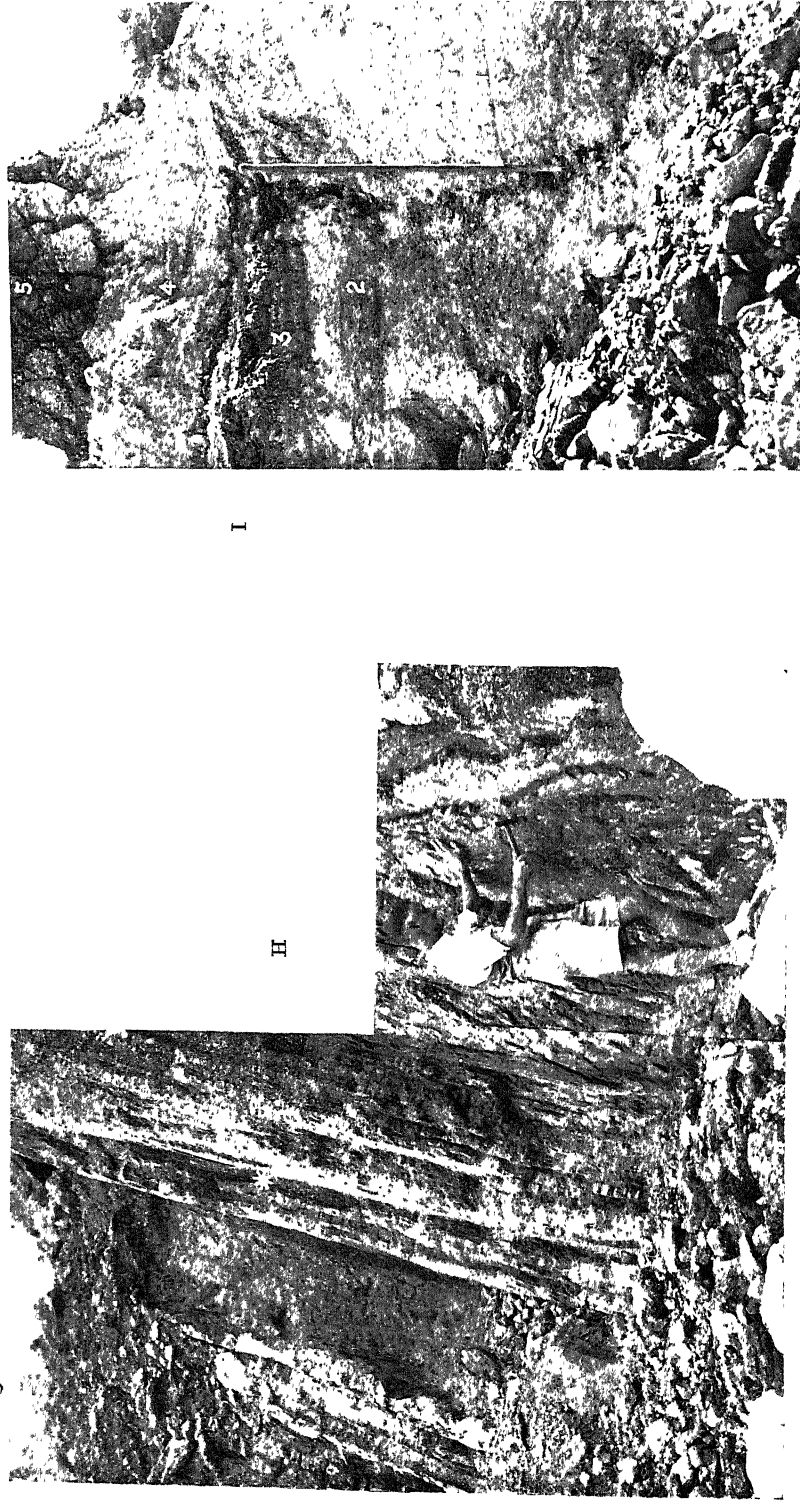
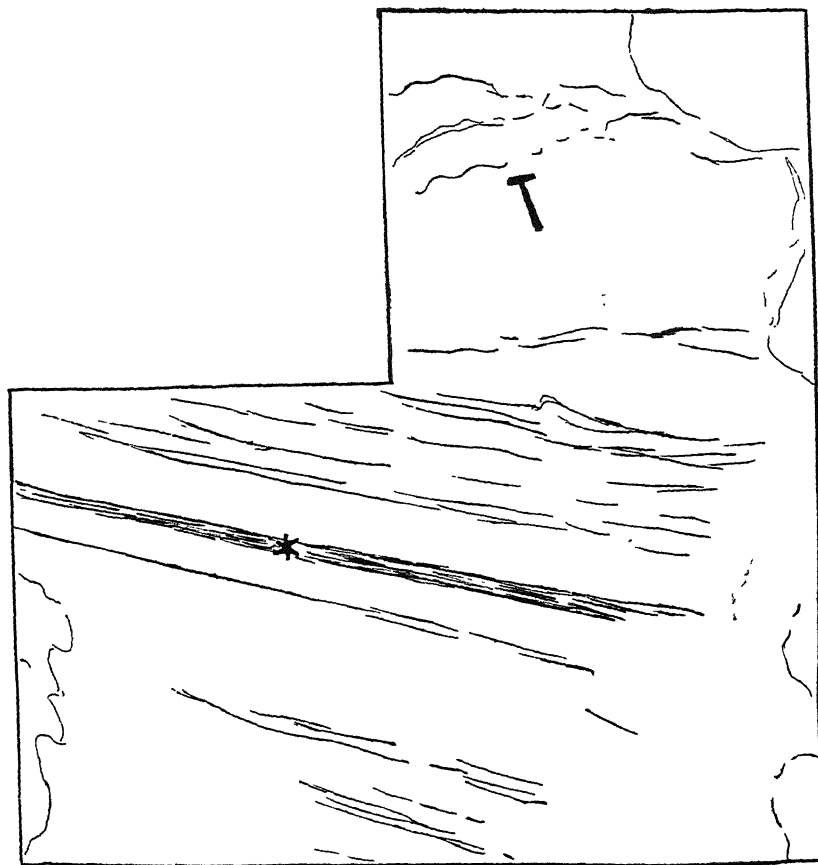
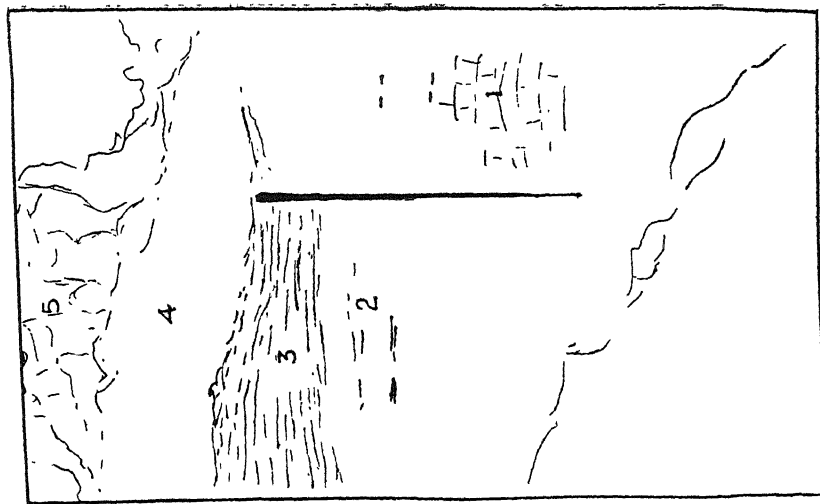


Photo: Sahni.



H. Bituminous Dolomites and Oil Shales, Fatehpur Maira gorge. The dark band * is particularly rich in microfossils. Dr. Lees' hammer rests against a Dolomite band (B. S. Photo., 2 Dec. 1946).



I. Section on left bank of Khewra gorge (Anderson's locality). 1, 2, 3. Dolomites and Oil Shales. 4-5, "Khewra Trap." 1, massive sandy Dolomite. 2 & 3, finely laminated sandy gypseous Dolomites with interbedded laminae of chocolate Oil Shales. 4, crumbly greenish grey rock with an ash-like aspect. 5, massive jointed Trap. The stick is about 5 feet long. (B. S. Photo., 4 Dec. 1946).

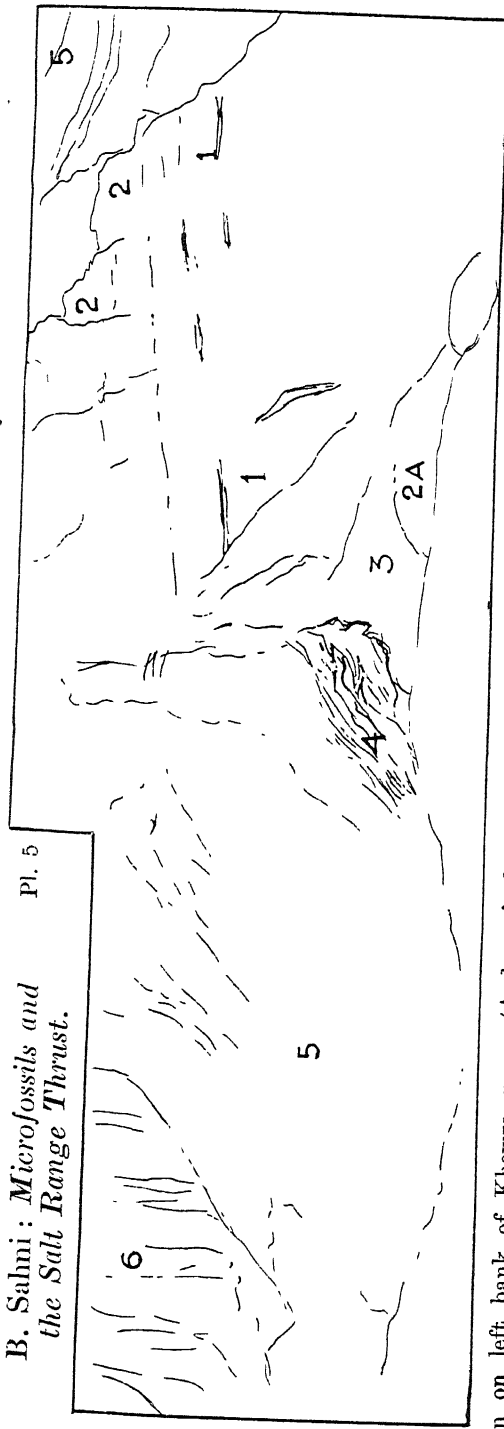
the Salt Range Thrust.



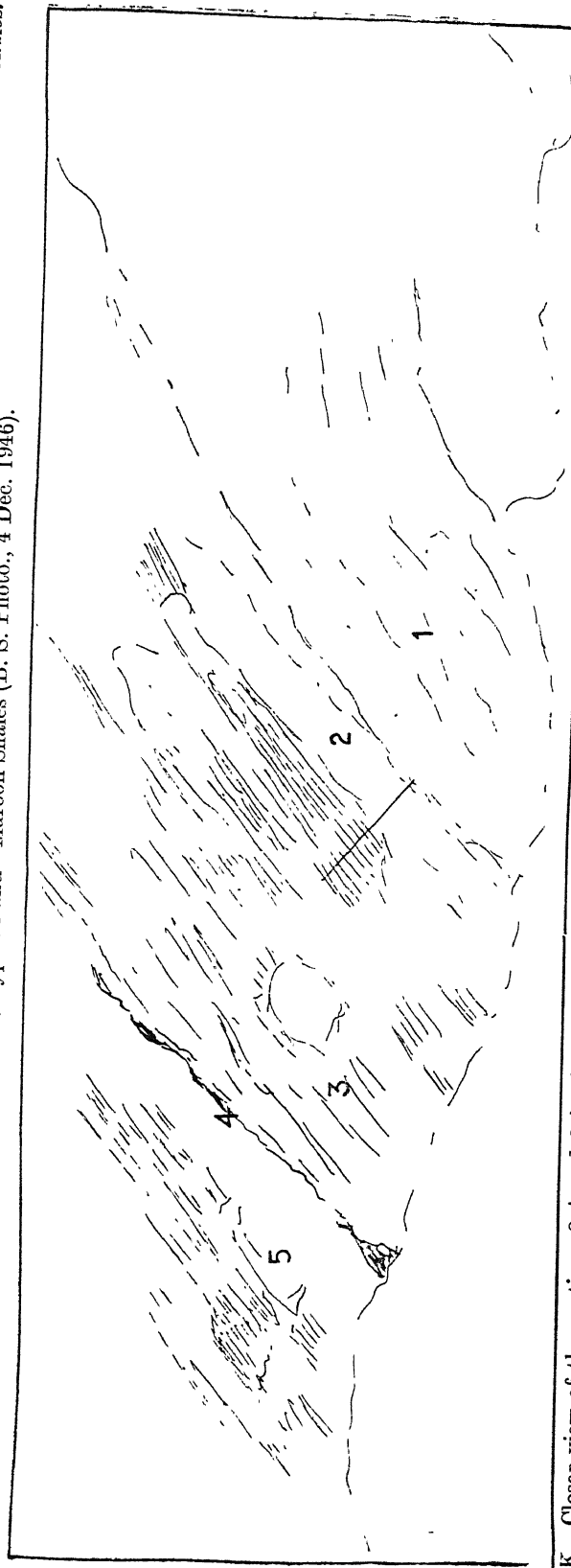
J

K





J. Section on left bank of Khewra gorge (Anderson's locality) including on the right the section shown in Photo L. 1. Infra-trappean Dolomites and Oil Shales. 2 "Khewra Trap" (? faulted down). 3. Supra-trappean Dolomites and Oil Shales. 4. Top Gypsum. 5, 6. Scree of Red Marl, Gypsum and Maroon Shales (B. S. Photo., 4 Dec. 1946).



K. Closer view of the portions 2-A and 3 in the above Section (B. S. Photo., 23 Oct. 1945.) 1. Massive Trap (upper surface indicated by stick). 2. Amygdaloidal upper zone of weathered Trap. 3, 4 & 5. Finely laminated Dolomites and Oil Shales. 4. Oil Shale which yielded

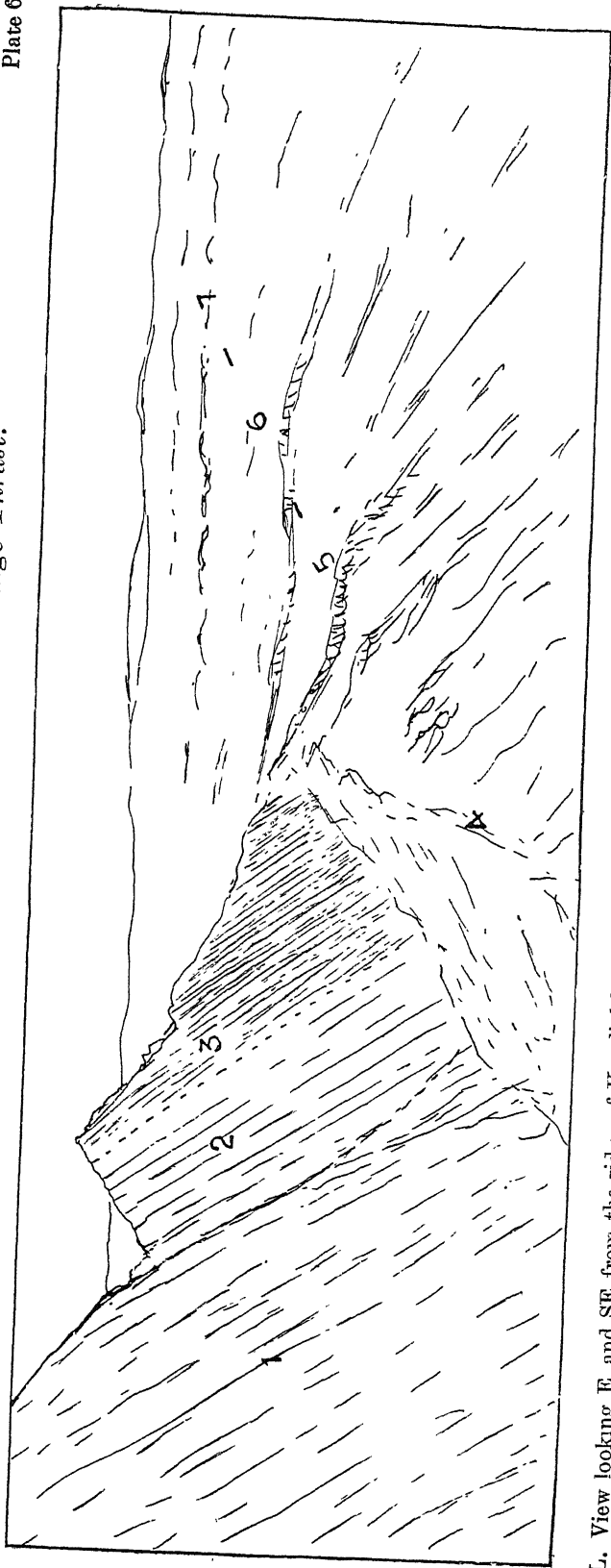


Photo : Sahni.

L

B. Sahni : *Microfossils and the Salt Range Thrust.*

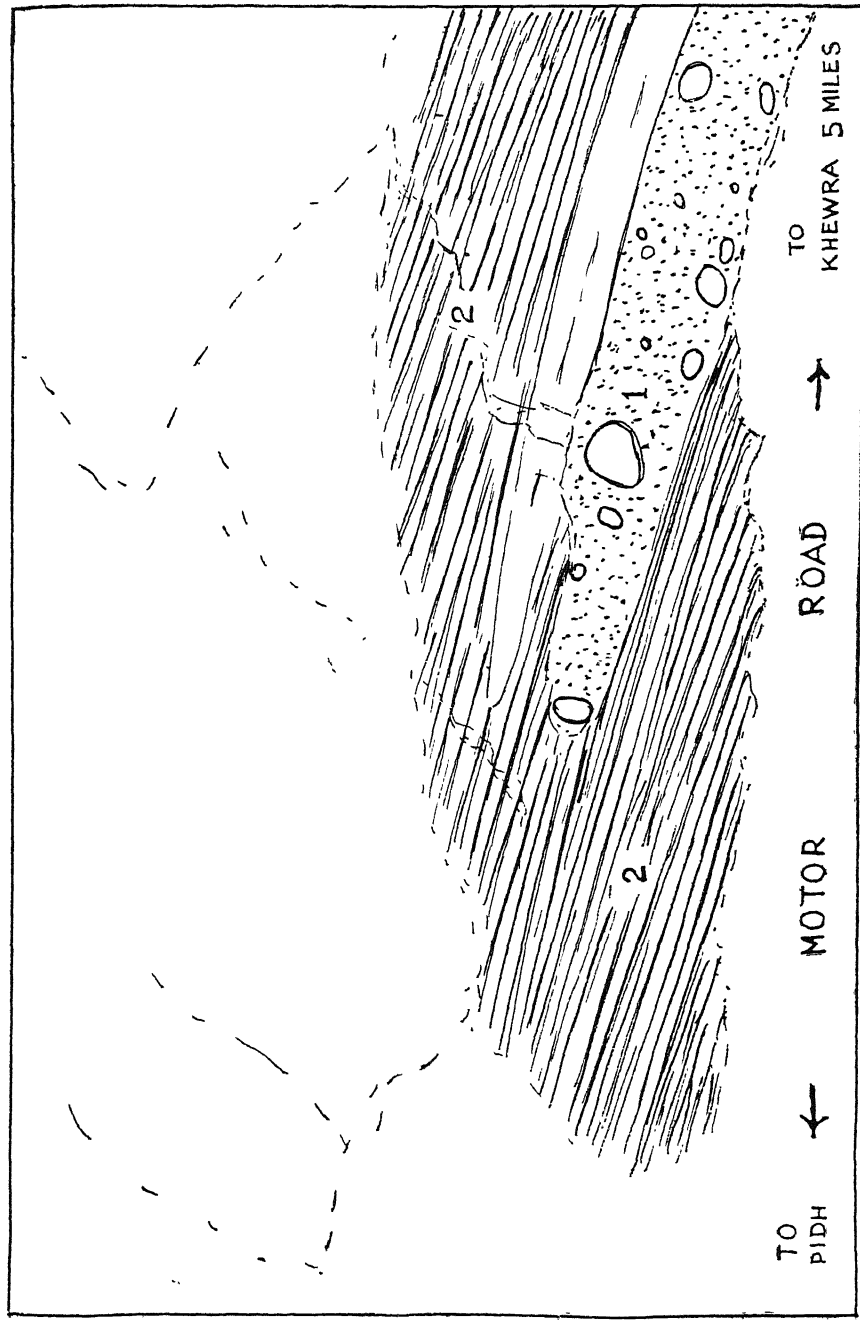
Plate 6



L. View looking E and SE from the ridge of Kamliyal beds north of Jalalpur, in the Eastern part of the Salt Range. (B. S. Photo., 26 Oct. 1945).
 1. Purple Sandstone. 2. Neobolus Beds. 3. Murrees resting with an unconformity on Neobolus Beds. 4. Kamlials. 5—6—7. Chinji, Nagri and Dhok Pathan Beds.

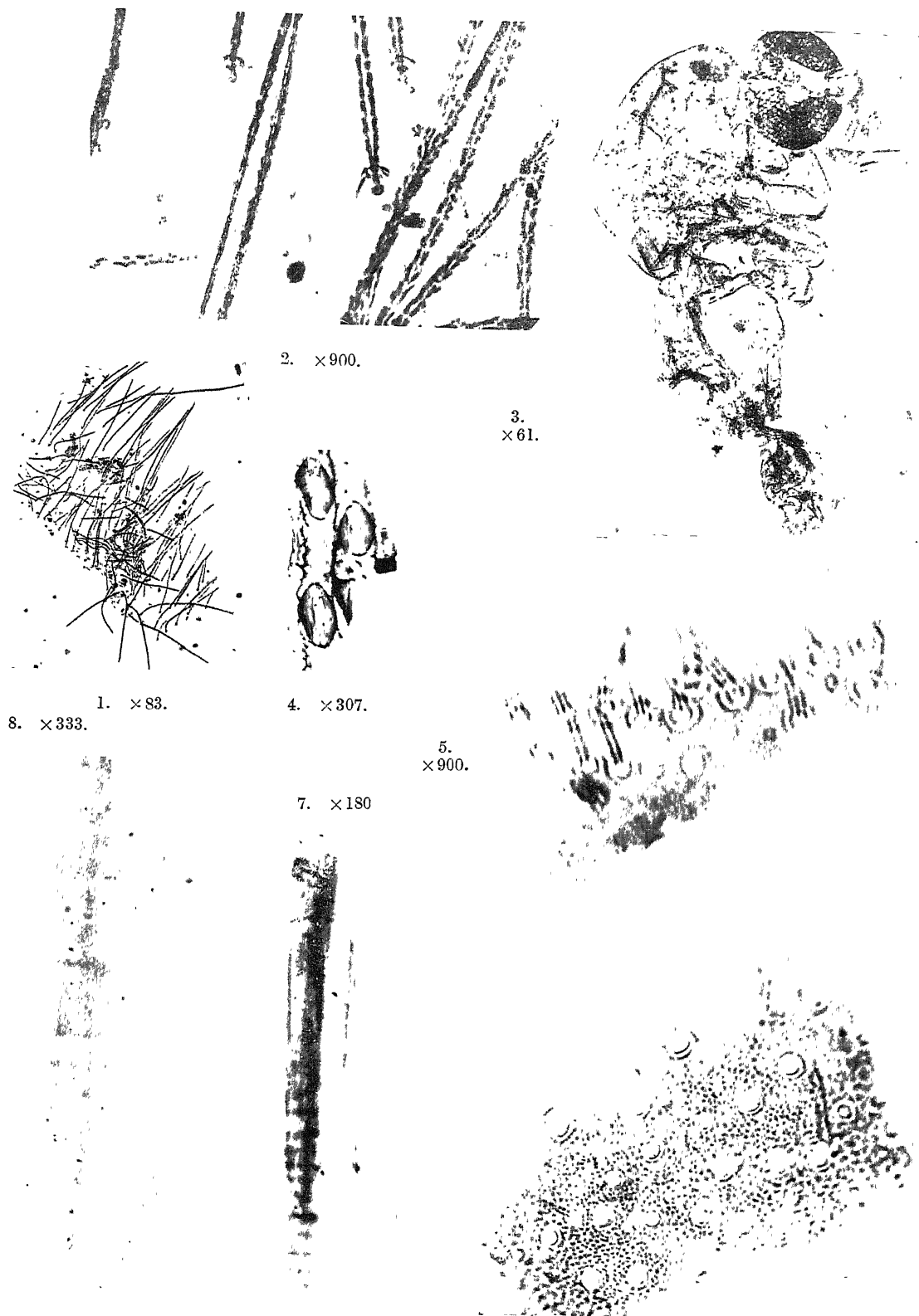


Photo : Sahni.



M. Section on the Khewra-Pidh motor road about 5 miles up from Khewra, showing a wedge of the Talchir Boulder Bed thrust into Salt Pseudomorph Shales. The bedding of the Shales is essentially undisturbed. (B. S. Photo., 28 Nov. 1946).

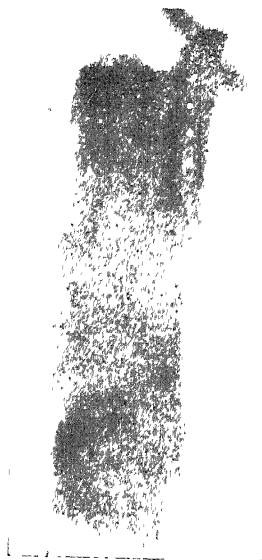
1. Talchir Boulder Bed. 2. Salt Pseudomorph Shales.



1-4. Fossils from Rocksalt and Kallar.

5-8. Fossils from Oil Shales,

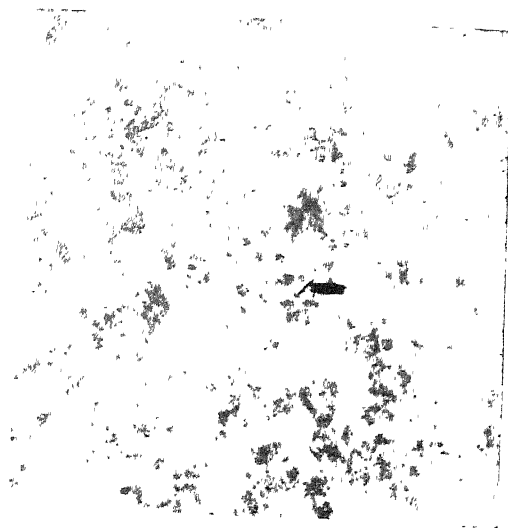
6 $\times 700$.



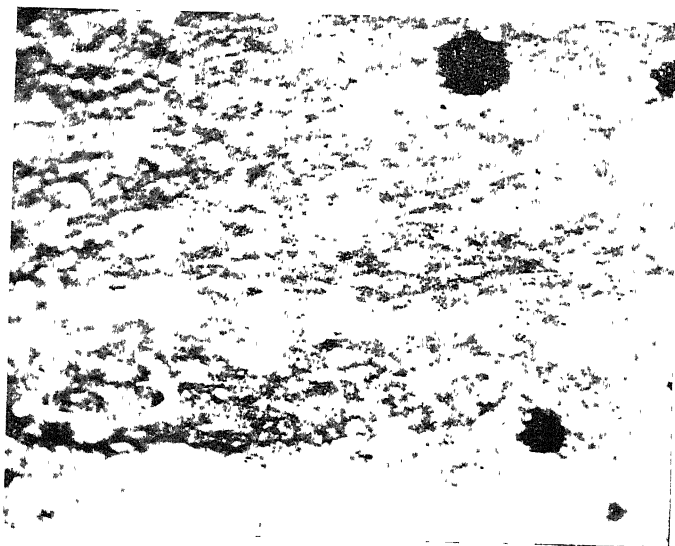
13. $\times 750$



12. $\times 207$



11. $\times 50$



9. $\times 57$



10. $\times 670$

Microfossils embedded *in situ* in Oil Shales.

9, 10. Oil Shales of Fatehpur Maira gorge (S. 57).

11-13. Oil Shales of Warchha gorge (S. R. E. 38).



14. $\times 335$.



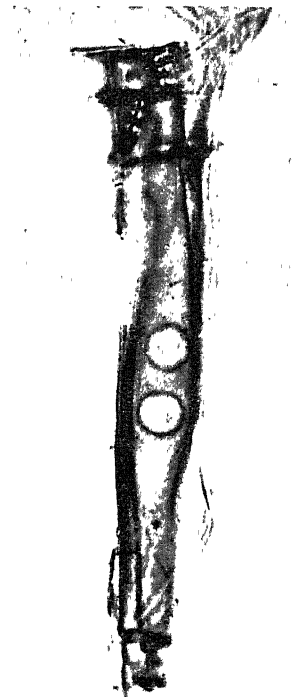
15. $\times 260$.



16. $\times 500$.



17. $\times 720$.



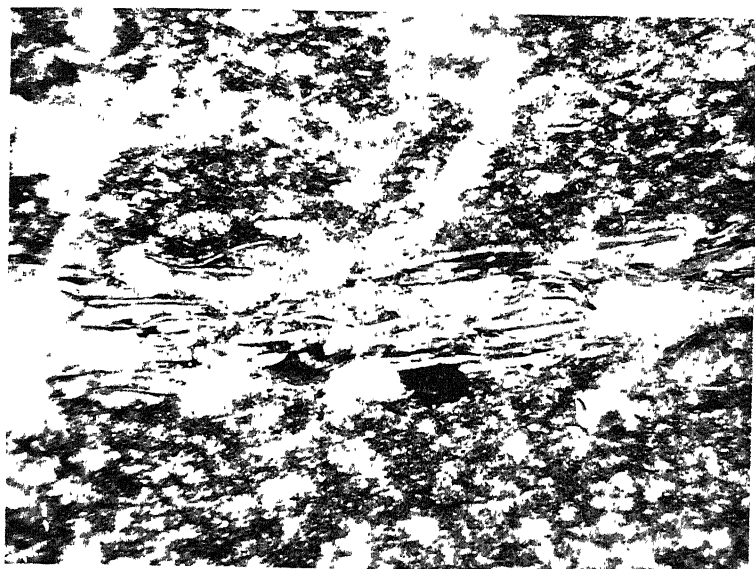
18. $\times 385$.

4-17. Microfossils from Dolomites, Warchha gorge.

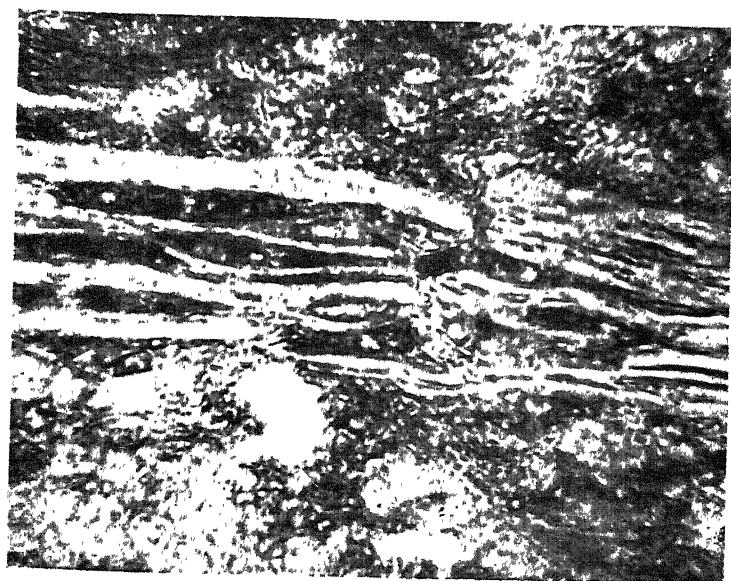
8. Microfossils from the Talchir Boulder Bed near Chittidil.



19.
× 75.

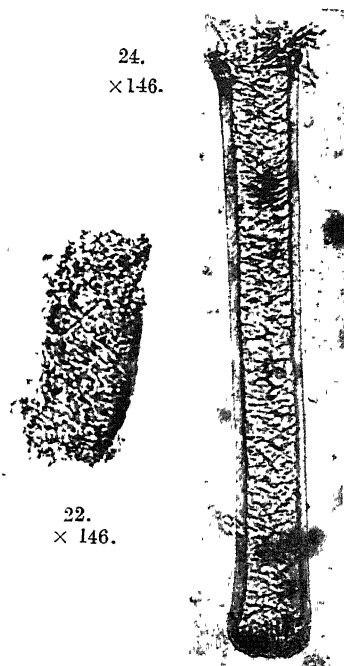


20. × 115.



S. Banerji photo.

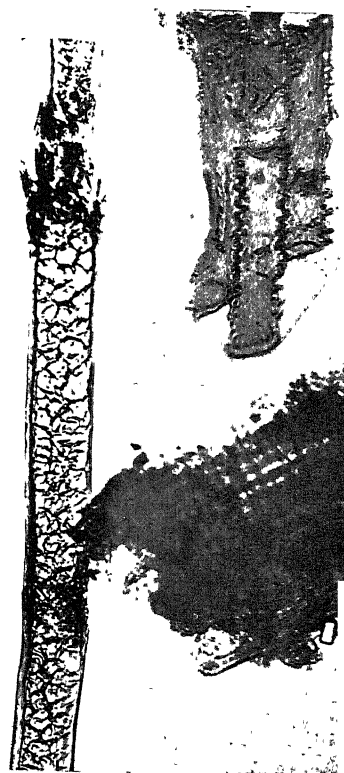
21. × 146.



22.
× 146.



24.
× 146.



25.] × 240.

23. × 146.

NOTE.

Mr. Gee has kindly sent me an extract from Soviet News, London, under the heading "Some achievements of Soviet Scientists by Sergey Vavilov, President of the Soviet Academy of Sciences", which reads as below :

"Good progress resulted from the Geology Institute's work. Among a number of results, most important was the discovery of spores of land plants in ancient Cambrian deposits. Hitherto, traces of land flora had only been observed in Devonian strata, that is, belonging to a period which dates back 300 to 350 million years at most. The discovery of such spores in Cambrian deposits proves that the lower land plants existed much earlier, at least 500 to 550 million years ago."

The earliest record of land plants so far known to me is the discovery by Miss Isabel Cookson of a flora of vascular plants in the Walhalla Beds of Victoria, Australia, which is regarded for good reasons as Silurian (Cookson 1935: On plant remains from the Silurian of Victoria, Australia, that extend and connect floras hitherto described. Phil. Trans. Roy. Soc. **225**: 127-148; Lang and Cookson 1935: On a flora including vascular land plants associated with *Monogaptus* in rocks of Silurian age, from Victoria, Australia. Phil. Trans. Roy. Soc. **224**: 421-449). The discovery now reported, of spores presumably of pteridophytic plants in the Cambrian, takes the history of land vegetation much further back, and palaeobotanists will await with great interest the publication of the details, including photographs of the plant remains.

At first this announcement would seem to raise the hope that the woody microfossils and cuticles recovered from the rocks of the Saline Series might have belonged, as Mr. Gee has suggested, to a Cambrian flora. There is, however, no evidence whatever that the reported Cambrian spores belonged to any such highly evolved groups as the gymnosperms or angiosperms, which are unknown in rocks older than the Devonian and Jurassic respectively. The present report, therefore, does not affect the question of the age of the Saline Series, which is now well established as Eocene on the combined evidence of stratigraphy and palaeontology.

B. Sahni.

5 May, 1947.

NOTE ON CORES FROM A BOREHOLE IN THE MAYO SALT MINE, KHEWRA

By

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(*With two tables*)

(Received 30 May 1945)

The Government of India have decided that the raw material—gypsum or anhydrite—for the manufacture of artificial fertilisers in India should be worked at Khewra. To study the sequence of strata below the main salt seams in the Khewra Mine a portable diamond drill was installed in Chamber 10 in the South Pharwala section of the mine and 231 feet of core was recovered as a result of boring during February, 1945.

A short description of the sequence of beds met with in the mine seems necessary to present a complete picture of the strata.

There are three main salt seams met with at Khewra: Buggy, Sujjowal and Pharwala, with a general northerly dip of 30° — 40° N.N.W.

1. *Buggy seam*:—This is the uppermost seam, which has yielded the best quality of salt for a very long period. Most of the salt shows big transparent cubic crystals. It is divided into two parts: (a) *The North Buggy seam*, mainly developed in the middle portion of the mine, with an average thickness of 25 feet; and (b) *The Main Buggy seam*, separated from the above by about 10 feet of marl. This is the thickest seam in the mine, which was even worked during the Sikh period. Average thickness 150 feet, thinning down in the eastern workings, to only 70 feet.

2. *Sujjowal seam*:—In the first few chambers (western portion) there is no intervening marl between the Buggy and Sujjowal seams. The average thickness of the marl in the east (noticed from Chamber 15 onwards) is 20 feet. The average thickness of the seam is 50 feet and it thins out to the east.

3. *Pharwala seam*:—This is composed of three separate seams in the western part but towards the east, beyond Chamber 32, the whole of it becomes marly. About 100 feet thick marl and thin salt separates the seam from Sujjowal. (a) *Upper Pharwala Seam*. Average thickness is 50 feet of salt which is not of very good quality. (b) *Middle Pharwala Seam*. About 50 feet of marl rich in magnesium and sodium sulphate separates it from (a). This seam is about 70 feet in thickness. It is characterised by very thin streaks of marl which give it a banded appearance. The dip is fairly high (almost vertical) in the northern portion as we go deeper. The bottom portion is characterised by a number of marl bands. (c) *South Pharwala seam*. About 50 feet of marl separates it from (b). This seam is only 15 feet thick in the western portion.

The bore hole was placed at the bottom of the lowest salt seam, namely the South Pharwala seam, to reveal the nature of strata below the salt seams that have been worked in the mine. It is unfortunate that the depth of the bore hole was restricted to 231 feet as no more drilling rods were available. Had it been possible to go deeper much more valuable information could have been obtained. It is hoped that at a later date results from greater depths will be made available.

The following cores of 2 inches diameter have been recovered from the bore hole. The diagrammatic section shows the sequence of the strata at a glance.

The first oil show was met with at a depth of 110—112 feet. The bore hole gave no evidence with regard to seams of gypsum, but the occurrence of dolomite containing oil and gas appears to open up interesting possibilities. The gas could be seen oozing out of the core on immersion in water, and on breaking it smelled strongly of petroleum. It also gave yellow stain with ether. The dolomite bed between 112 feet and 119 feet contains saline

pellets and is a sort of fault breccia, and as a matter of fact this re-formed stratum continues to a depth of 120 feet. The results of analysis of a sample of do omite from a depth of 113 feet are given below.

CO ₃	=	33.60
Cl	=	18.99
Ca	=	27.72
SO ₄	=	0.54
Mg	=	5.18
Insoluble	=	3.60
Fe ₂ O ₃ + Al ₂ O ₃	=	0.39
Moisture	=	2.27
Total:	=	92.29%

Rest undetermined; PO₄ present in traces.

The occurrence of grey salt, which is very similar to the 'Kohat salt', at a depth of 142 feet and downward, is also remarkable. The mixed up formation for five feet, viz. 147 feet to 152 feet, composed of dolomite, gypsum and salt showing slickensides, points to another fault zone. The next oil shows occur in dolomite at depths of 193½ feet to 194 feet and 206 feet to 208 feet.

It appears to me that a study of these cores may furnish useful evidence with regard to the age of Saline Series in the Punjab Salt Range. From correlation with the sequence in oil horizons of the Potwar Plateau and Kohat in the trans-Indus Range I worked out that probably the salt is Lower Chharat or Kirthar (*Lamba 1944*). Colonel L. M. Davies (1944) also held the same views independently. Professor B. Sahni (1945) who discovered several plant fossils in samples of marl, dolomite and oil shales from the Saline Series, has also come to the conclusion that the palaeontological evidence, combined with the stratigraphical data, proves an Eocene age. According to this basis the oil which originated in the Laki and Ranikot limestones lies below the Saline Series. The occurrence of three oil shows in the bore hole lends a strong support to this view, and it is hoped that deeper boring may reveal more

valuable evidence. The occurrence of grey salt which in Kohat is admitted to be of definitely Tertiary age is also a strong point in favour of a Tertiary age for the Saline Series. The salt from some of the salt quarries in Jatta (Kohat) smells so strongly of petroleum as if it had been freshly taken out after immersion in the same. It is not possible to imagine another age for the oil than that established from the workings in the Potwar Plateau. *Therefore the evidence from the bore hole goes a long way in support of the Tertiary age of the Saline Series.*

Although this view about the age of the Saline Series is opposed to the view held by Dr. Murray Stuart in his valuable paper (1919), it is in agreement with the view that the trans-Indus and cis-Indus salts are of the same age, whatever it be. The oil indications from the bore hole have more important bearing on the sequence in the trans-Indus Range than in the cis-Indus.

Also the opinion expressed by Dr. Murray Stuart with regard to the origin of gypsum and arrangement of various salt zones is borne out by the results of the boring. There is a large amount of gypsum capping the hills in which the salt mine is situated and also there is gypsum above the salt; while below a depth of 108 feet gypsum, salt and dolomite have been found mixed together. This could not have occurred in original stratification. But a flow structure as expounded by Murray Stuart explains the present re-arrangement. This fact is also clear that the gypsum is not the original sedimentary deposit. No tectonics can explain its present unconformity with the salt zones and banding in salt. Had it been the result of a normal process from evaporation of a salt lake, gypsum being least soluble should have been separated first and it should have all been met below the salt. I agree with Murray Stuart, therefore, that it is a contact mineral formed by reaction of sulphuric acid set free from iron sulphide associated with salt on calcareous matter. "It is usually formed at the junction of salt formation with other sediments containing calcium carbonate or holding water carrying calcium carbonate in solution."

As stated above, grey salt similar to that of the Kohat Zone was met with from a depth of 142 feet downwards. Dr. Murray Stuart had already made this observation from an exploratory drift in Chamber 12 Pharwala. I am in entire agreement with him about the arrangement of the various salt zones, placing the Khewra Salt Zone at the top and the Kohat Salt Zone at the bottom, as proved from the boring. The Warcha Salt Zone and/ or Kalabagh

Salt Zone is probably represented by the white salt above the grey salt. "The Kohat zone corresponds probably with the Anhydrite zone of Stassfurt, the Kalabagh zone probably to something between the Anhydrite and Polyhalite zone, the Warcha zone to something between the Polyhalite and Kieserite zone, and the Khewra zone to about the Kieserite or something between the Kieserite and Carnallite zone".

Fourteen samples of the core from various depths have been sent to Professor B. Sahni at Lucknow for microfossil analysis.

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ADDENDUM.

(Received 22 November 1945).

The above note on the cores from a bore hole in the Mayo Salt Mine Khewra was written in March 1945. In October 1945 two more bore holes were drilled at the foot of the mine hill. As the strata drilled through form the base of the Saline Series and have an important bearing on the age of the series, it has been deemed fit to add this note.

The sections of the two bore holes are shown in the enclosed diagrams.

No. 1 bore hole (A) was drilled for the exploration of gypsum at foot of the hill near the eastern extremity of the departmental boundary line, the elevation of the locality being 850 ft. It was stopped at a depth of 46 ft. as no gypsum was encountered, though gypsum was outcropping on the hill side.

The following strata were met with:—

- 0 to 27 feet. Limestone pebbles. (No recovery: probably soft clay bed.)
- 27 to 28 feet. Dolomitic limestone.
- 28 to 29 feet. Limestone.
- 29 to 38 feet. No recovery: probably soft clay
- 38 to 39 feet. Limestone and dolomite containing foraminifera.
- 39 to 42 feet. No recovery: soft clay.
- 42 to 44 feet. Limestone (fossiliferous).
- 44 to 46 feet. Dolomite with green specks (glauconite) (fossiliferous).

No. 2 bore hole (B) was drilled at a distance of 102 feet north-east of No. 1 bore hole, on slightly higher ground over a bed of gypsum, the elevation of the locality being 870 feet. The following strata were passed through:—

- 0 to 4 feet. Gypsum.
- 4 to 6 feet. Red clay.
- 6 to 15 feet. Gypsum.
- 15 to 16½ feet. Gypseous clay.
- 16½ to 20 feet. Gypsum.
- 20 to 25 feet. Gypsum with thin clay bands.
- 25 to 40 feet. Gypseous clay.
- 40 to 55 feet. Red clay. (No recovery from 50-55 feet).
- 55 to 65 feet. Limestone and dolomite, some with green specks (fossiliferous).
- 65 to 66 feet. Red clay: no recovery.
- 66 to 67½ feet. Dolomite, cream colour, with specks.

A close study of the formations met with in the two bore holes shows that as bore hole No. 2 was placed 20 feet higher than bore hole No. 1, we meet

with 25 feet thickness of gypsum and some red clay in No. 2 bore hole. Therefore the top of No. 1 bore hole corresponds to a depth of 25 feet in No. 2. A length of 27 feet from surface in No. 1 bore hole, from which portion there was no recovery, correlates with 25 feet to 55 feet of gypseous and red clay strata in No. 2 bore hole.

At depths below 27 feet in No. 1 bore hole and below 55 feet in No. 2 bore hole we meet with beds of limestone and dolomite which are rich in foraminifera. Several nummulites and alveolinae are easily recognisable which prove the beds to be of Laki age. The green specks which are numerous in the dolomite at 46 feet in No. 1 bore hole are also visible in the dolomite bed met from 60 feet to 65 in No. 2 bore hole, though the specks are sparsely distributed.

As the formations of the two bore holes placed at a distance of over a hundred feet apart can be correlated, the bed of limestone below gypsum is continuous. The possibility of its being only a consolidated gravel can be eliminated. Also, had this been a bed formed by transported material we should have come across some other hard material like magnesian sandstone, which is in greater proximity and is more widely distributed in the bed of the gorge.

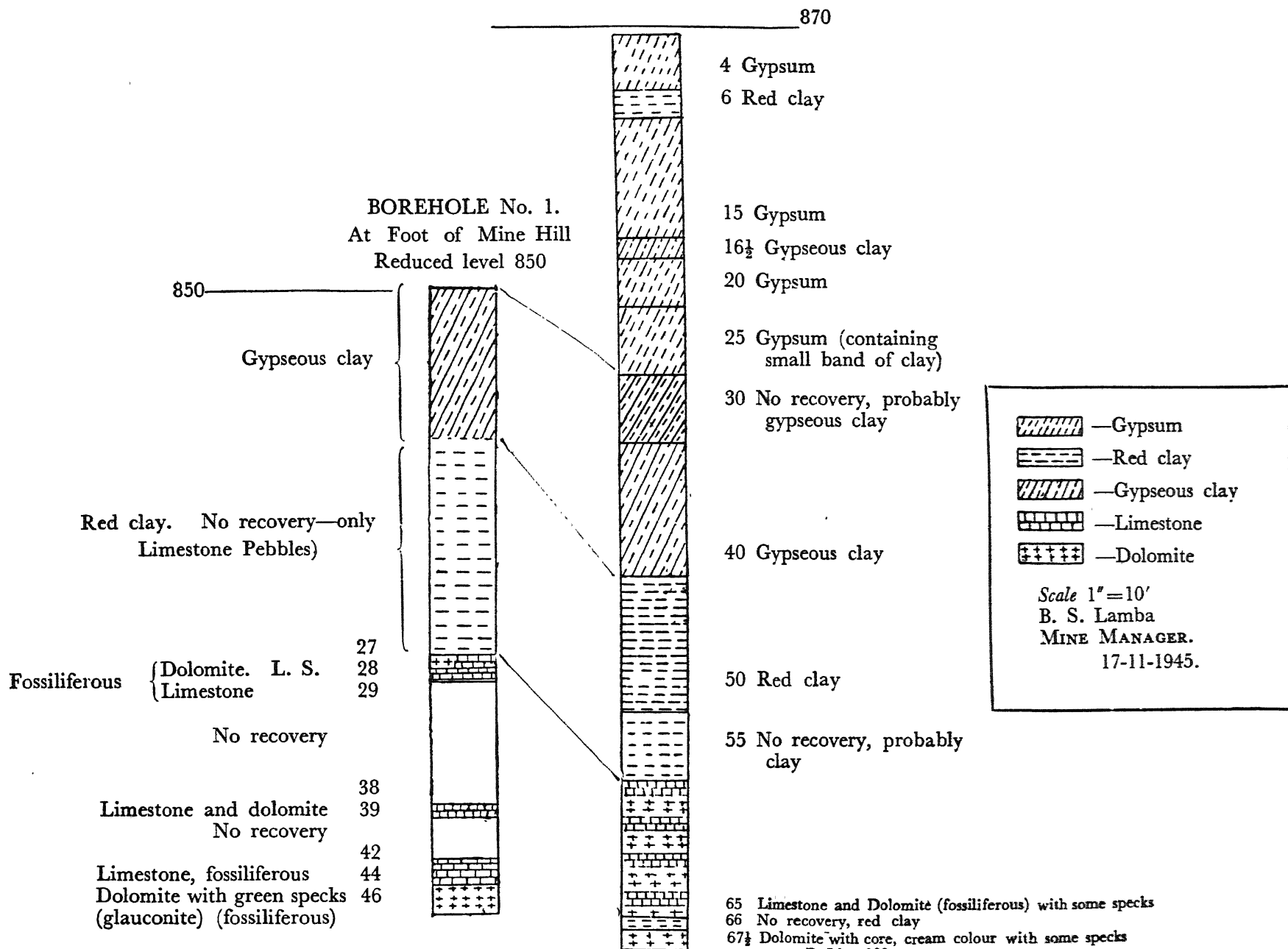
Two samples of dolomite have been analysed by the kind courtesy of Mr. A. S. Irvine of the Alkali and Chemical Corporation of India Ltd., Khewra. The results are as follows:—

<i>Qualitative Analysis.</i>	<i>Sample No. 1 (Bore hole No. 1 depth 46 feet.)</i>	<i>Sample No. 11 (Bore hole No. 2 depth 67 feet).</i>
R_2O_3 (Fe_2O_3 & Al_2O_3) ..	Present.	Present.
SO_4 ..	Trace.	Nil.
$CaCO_3$..	48.25 per cent.	44.5 per cent.
$MgCO_3$..	37.38 per cent.	35.13 per cent.

The close association of limestone and dolomite beds also shows that the beds are in situ and form the base of the Saline Series. Therefore, while the evidence from the cores obtained from the bore hole at the base of the salt seams in the Mayo Mine was inconclusive, the results of the two bore holes described above seem to provide conclusive evidence in support of the Lower Kirthar (Eocene) age of the Saline Series.

BOREHOLE No. 2.

At Foot of Mine Hill (102 ft. E of No. 1).
Reduced level 870.



COMMENTS ON THE FIRST SYMPOSIUM ON THE AGE OF THE SALINE SERIES IN THE SALT RANGE.

By

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(Received 21 September 1945)

When a diversity of views exists upon a scientific problem there is nothing so useful as a symposium, held in its true sense with liquid refreshment or more formally with the reading of papers, to bring these differences to a head; for thus will be found what has still to be done to resolve these differences, should this be possible. All geologists interested in the problem of the age of the Saline Series of the Salt Range must therefore welcome the meeting that has been conducted by Prof. Birbal Sahni, and the later one that is projected for the autumn of this year.

Prof. Sahni has invited me to make some contribution to this second symposium. I doubt if I am a suitable person to participate, unless the imbibition of refreshment without contribution be considered helpful. For I have been to the Salt Range only once, when I paid a brief visit to Mr. Gee in the field in my then capacity of Director of the Geological Survey of India. My method during such visits was to act as counsel for the prosecution in order to help the officer in the field to defend his views. On this occasion Mr. Gee thought he had found conclusive evidence for the Tertiary age of the Salt Marl, and took me to see an occurrence of Ranikot foraminifera enclosed in the salt. He had, however, during the previous days, shown me many occurrences of disturbed strata in the Salt Range with beds thrust into unexpected places; so I advised him not to burn his boats (I should have said ladders!) and come down definitely on the Tertiary side of the fence unless he was quite certain that these Ranikot fossils were really *in situ* in the beds with which they were associated. I gather that Mr. Gee and others decided later that these fossils were not *in situ*, and that Mr. Gee has since found other evidence which, both in his own opinion and in that of other competent geologists who have examined the ground, supports the view that the Saline Series is in its normal position when below the Purple Sandstone series.

Although I am not entitled to a view on this problem based on a personal survey of the ground, I have long taken an interest in the various papers that have been written; but because of the conflict of evidence I have found it necessary to remain balanced on the fence. I must confess that Prof. Sahni's discoveries nearly brought me down on the Tertiary side. I have, however, recently sipped at the symposium presented in the Supplement to Part 6 of Volume 14, Section B, of the *Proceedings of the National Academy of Sciences, India*. From this I find that the conflict is now between the field geologists and the palaeontologists, each placing his trust in the type of evidence he is accustomed to value. Normally there is no conflict between stratigraphical and palaeontological evidence. Why is there a conflict in the present case? It appears to me that the fundamental reason is the plasticity, the incompetence in the stratigraphical sense, of the Saline Series. This plasticity under pressure will permit salt to be squeezed into any place where the pressure is less, and added by the solubility of salt in water will permit any available foreign object, stone, stick, fossil, or recent insect, to be incorporated in the salt, if the conditions are suitable. Consequently, if Mr. Gee on the visit mentioned above had shown me a trilobite entombed in the salt I should still have advised him not to come down on the Cambrian side of the fence until he had made sure that the trilobite was in place.

In summary, although I am still reluctant to express a definite opinion on this problem, I must say that if, as now seems to be the case, the field geological evidence supports strongly the view that the Saline Series is in its correct stratigraphical position at the foot of the Salt Range succession, then in view of the incompetence of the salt beds the nature of their fossil contents cannot be accepted as taking precedence over the stratigraphical results, which have been obtained by the continuous mapping of the whole area. This means that temporarily at least I am in favour of a Cambrian or pre-Cambrian age for the Saline Series; and that I cannot help continuing to hold this opinion until the most indubitable evidence has been secured that fossils or sands of later age cannot have reached their present position due to the plasticity, including solubility, of the salt, so that they can be accepted as original constituents thereof.

AGE AND ORIGIN OF THE SALT DEPOSITS OF NORTH-WEST INDIA

By

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(Received 29 November 1945)

When contributing to this discussion last year (1944), I recalled the stratigraphic facts which indicate the trapping and desiccation of the waters of a marine gulf, in the Kohat-Potwar region of North-West India, at the close of Laki (Lower Eocene) and commencement of Lower Chharat (basal Khirthar, or early Middle Eocene) times, under conditions apparently ideal for the accumulation of great salt deposits in the southern and south-western parts of that basin. Some of the other contributors appreciated this point; for references to that marine gulf, in connection with these deposits, were made by Prof. Sahni (1944, *pp. vi, xxv*), Mr. Gee (1944, *p. 279*) and Mr. Wadia (1944 *p. 318*). It was, however, ignored by Sir Cyril Fox, who claimed (1944, *p. 236*) that he could find, in the Eocene of N. W. India, "no epoch when marine and climatic conditions could favour the deposition of salt on a considerable and widespread scale", but that there was "nothing impossible about the geographical aspects of a pre-Cambrian to Cambrian age for the Punjab Rock-salt occurrences". Sir Cyril has obviously not grasped the results of my work (summarised in 1940) on the Eocene stratigraphy of N. W. India, and I have yet to learn that similar reconstructions have been published of the pre-Cambrian and Cambrian geographies of that region. Sir Cyril repeated his ideas in a communication to *Nature* (1945); and I replied, as regards this point, in a letter (1945) to which there has so far been no rejoinder. I showed that the Eocene is the one period when known structural evidence indicates, that suitable topographical conditions did exist, for producing thick salt deposits in north-west India.

I stress the word "topographical", for topography is the decisive factor here. It is the topography of the Jordan valley which decides that saline accumulations shall be at the Dead Sea end of it; and it is the topography of the Caspian basin which decides that saline accumulations shall be on its eastern margin, and chiefly in the Karaboghaz Gulf. It is not enough to claim an arid climate and marine waters, for there will be no resulting thick deposits

of salt unless the local topography is one of those relatively rare kinds which ensure accumulations of marine salts far in excess of the amounts proper to the local marine waters themselves.

Stratigraphy, therefore, favours a basal Khirthar age, for the Salt of the Kohat-Potwar region (1); and it seems that Sir Cyril Fox's allies in claiming a basal Cambrian age for the eastern salt differ sharply from him by accepting the Khirthar age of the Kohat salt, at least. They apparently find no difficulty in recognising that conditions favoured an Eocene collection of salts west of the Indus (2). Sir Edwin Pascoe (1944, *p.* 267), Mr. Pinfold (1944, *pp.* 239-240) and Mr. Gee (1944, *pp.* 279, 288-290, 305) are as emphatic on this point as Prof. Sahní (1944, *p.* xxvii, etc.), Messrs. Wadia (1944, *p.* 214) and Lahiri (1944, *p.* 332), and myself (1944, *p.* 225, *ff.*). And that, I may say, emphasises my point in contributing to this discussion; for I have shown that the Cretaceo-Eocene marine basin, to whose temporary desiccation in early Khirthar times the Kohat salt deposits must be referred, equally covered the Potwar region, and so may well have also left saline deposits east of the Indus (whose present course, one need hardly say, represents no Eocene division of that basin) (3). Thus Eocene topography affords good presumptive reason for finding saline collections east of the present Indus valley as well as west of it. Nothing approaching the same topographical evidence exists for attributing any other age to either eastern or western salt. In the absence of

(1) The Kohat gypsum, sometimes intercalated with the early levels of the normally fluviatile Lower Chharat beds, is obviously correlated with the accompanying dolomitic lenticles etc., and with the underlying rock-salt. It has also, in places, been found to contain *Nummulites* and *Alveolina* (Wadia and Davies, 1929, *pp.* 211-2; *Pls.* 10-11). According to Gee (1944, *p.* 288) "there is no doubt whatsoever of the Eocene (probably basal Khirthar) age of the gypsum-dolomite beds". The fishes found in these levels (Gee, 1934, *p.* 461; 1938, *p.* 315; 1944, *p.* 288; Pinfold, 1944, *p.* 241; Lahiri, 1944, *p.* 332) were considered by Dr. E. I. White, to whom they were originally sent "for examination and description" (Fermor, 1934, *p.* 20), and who differs in this respect from Dr. Hora (1937), to be fresh-water forms (Cyprinidae, etc.). I therefore suggested (1940, *p.* 491) that they had been brought down by the early Indus River.

(2) According to Pinfold (1944, *p.* 240): "It is now generally agreed by all the geologists who have field knowledge of the Kohat Salt Region that the Kohat Salt Series is Eocene (Lower Chharat)...Salt forming conditions in the Eocene are thus proved and accepted".

(3) Thus Gee himself (1944, *p.* 279) talks of "early Khirthar" Salt concentrations taking place in "a marine gulf in the Kohat-Potwar area"; so why could not some of the concentrations have been in the Potwar, as he formerly believed? This would certainly, as Middlemiss remarks (1944, *p.* 268) afford a more "harmonious" conclusion than we find in Mr. Gee's later views.

detailed knowledge of geographical changes in north-west India at any other period, appropriate topographical conditions are simply assumed to suit the date attributed to the deposits, on some such plea as that there is "nothing impossible" about them. But that says little for their actual existence.

I have not examined the particular exposures which are held, by Mr. Gee (1945) and others, to prove that the eastern salt conformably underlies the Cambrian beds of the Salt Range, for most of my field work was on beds to north and west of that Range; but I could illustrate, from the latter, how deceptive field relations can be, apart from fossil evidence. I myself and other geologists likewise, have sometimes formed confident opinions as to successions, on the strength of apparently clear field testimony, which the discovery of fossils has afterwards proved to be mistaken. And it certainly seems that there are grounds for suspecting the field evidence claimed for the basal Cambrian age of the Punjab Salt. The very arguments of those who stress the plasticity, mobility, solubility etc. of salt deposits, cause one to doubt the significance of local appearances of salt below Cambrian beds. On the other hand, the saturation (as Prof. Sahni and his colleagues have shown) of not only the salt itself, but also of the associated dolomite bands and oil shales, with minute organic remains incompatible with early Palaeozoic age but quite compatible with an Eocene date, is most difficult to account for on any theory of subrecent infiltration. Such infiltration would, it seems reasonable to suppose, be local and highly varied rather than general and seemingly uniform. The stratification of bitumen etc., as stressed by Lahiri (1944, *p.* 329, *ff.*) supplements and underlines this evidence. The testimony of heavy minerals, as indicated by Evans and Majeed, is also to the same effect (*Cates*, 1944, *p.* 321; *Sahni*, 1944, *p.* 324); and according to Lamba (1944, *p.* 223) the actual stratigraphic sequence north of the Salt Range, at Khaur, is similar to that west of the Indus.

Decisive evidence, one way or the other, should be afforded by determining the helium age of the Khewra trap, which is admittedly (*Gee*, 1944, *p.* 292) interstratified with the eastern salt. Should its age indicate an Eocene date rather than an early Cambrian one, that would not be anomalous; for even if other Lower Chharat beds, so far as yet known, contain no local outflows of trap (*Pinfold*, 1944, *p.* 241), the fact remains that early Tertiary volcanic activity did exist in the Kohat-Potwar region. Mr. D. Balsillie noted the presence of volcanic ash in my slides of the Hangu Breccia of the Miranzai Valley (*Davies*, 1930, *p.* 11, *f.n.*), that breccia being of Ranikot age; and the

disturbance of Ranikot beds near the volcanic vent of Kapianga Mountain (or "Bakkarkanch", 70°32'E.: 33°22'N.), referred to by Wynne (1879, p. 111), shows that this activity continued in the north-western part of the basin until after Ranikot times. So it would be fitting enough if similar activity were found to have existed, at about the same time, in the south-eastern part of the basin. The significance of the silicification both of the Khewra trap and of the Nummulitic limestones near Khewra, has been well emphasised by Chhibber (1944, p. 247).

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SOME FOSSIL ARTHROPODS FROM THE SALINE SERIES IN THE SALT RANGE OF THE PUNJAB.

By

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(*With ten figures*)

(Received 4 December 1945)

ABSTRACT.

In addition to the extinct dipterous fly *Chironomus primitivus*, described in an earlier paper, the microfossils discovered by Professor Sahni in rock salt, salt marl, dolomite and oil shale from the Salt Range of the Punjab comprise pieces of chitin and integument of several other terrestrial Arthropods. Although most of these microfossils are too fragmentary to be referred to species or genera, they should greatly simplify the problem of the age of these strata and are therefore briefly described in this paper. It has been possible to recognise in the material the larvae of a Collembolan and a Dermestid (Coleoptera), several pieces of Orthorrhaphous Nematoceros Diptera and of Homoptera, as well as ova and protonymphs of gamasid mites. None of these Arthropod existed before the Carboniferous period and the fragments described in the paper mostly belong to Tertiary forms.

INTRODUCTION.

Although the sedimentary origin of the saline deposits in the Salt Range of the Punjab was demonstrated by Christie as early as 1914, these strata have generally been believed to be unfossiliferous (*Christie* 1914). Recently however, Professor Birbal Sahni succeeded in disproving this belief and thus opened up an entirely new field of palaeontological research by his brilliant discoveries of microfossil remains of fragments of wood of Angiosperms and Gymnosperms, pollen grains, leaf cuticles, chitinous fragments of various terrestrial Arthropods, etc. Since their first discovery (*Sahni and Trivedi* 1943) of microfossils in Rock-salt and kallar in 1943, Sahni and Trivedi (1944) have found microfossils in the dolomites and oil shales of the Saline Series also.

The find of Arthropod fossils in the saline deposits is of special interest since only rarely, as for example in Copal and Ambers, does one come across the more or less completely preserved original tissues of these organisms. The

microfossils are surprisingly much better preserved than Amber specimens. This excellent condition of the material is no doubt due to the great preserving qualities of salt. Unfortunately, however, most of the specimens are extremely fragmentary and in some cases the organisms appear to have suffered a considerable amount of damage before becoming 'embalmed' in the salt. It is thus not always possible to refer the material to species, genera or sometimes even families. The only clues are often certain obscure patterns of sculpturing, the nature and the proportions of the segmentation, the microstructure and general distribution of spines, setae, hairs, etc., characters easily overlooked even in living forms.

In 1944 I studied part of his material and published brief descriptions (*Man* 1945) of some of the more complete specimens, and deferred reporting on the rest pending fuller study. In the meanwhile, Messrs. B. S. Trivedi and R. N. Lakhanpal had found other fossil remains of Arthropods. Recently Professor Sahni very kindly placed the entire material at my disposal and I have also availed myself of re-examining the earlier material. Although, as already mentioned, definite generic reference is not possible in most cases, the find of these Arthropod remains should greatly simplify the problem of the age of the Saline Series, as none of the remains studied by me appear to be older than the Cretaceous. I have therefore briefly described here all the fragments of Arthropods so far discovered.

I take this opportunity of expressing my sincere thanks to Prof. Dr. Birbal Sahni, Department of Botany and Geology, Lucknow University, for his kindness in placing this interesting material at my disposal and for numerous other courtesies and to Prof. Dr. L. P. Mathur, Head of the Department of Biology, St. John's College, Agra for facilities for work and constant encouragement.

DESCRIPTION.

Class	..	..	Insecta.
Subclass	..	..	Apterygogenea.
Order	..	..	Collembola.

On slide No. 41 there is a relatively large piece of the slightly chitinated anterior part of the thorax probably of a Collembolan larva, obtained from Rock Salt at Khewra (Fig. 5). The specimen is nearly colourless (except for the slight reddish tinge due perhaps to the safranin employed when the rock was dissolved in the laboratory), transparent and measures about 155

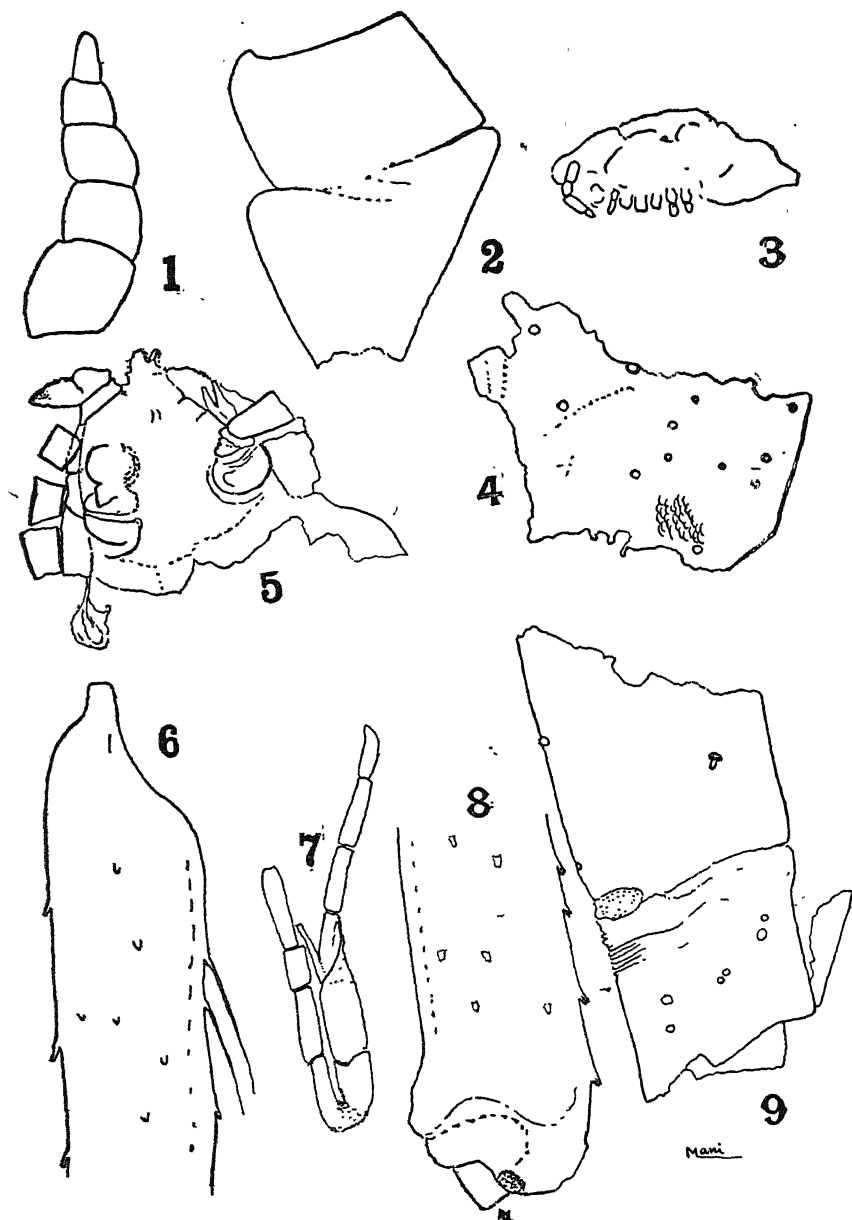
microns long in the middle and 220 microns broad at the posterior end. The head and the part of the thorax to which it was attached are missing. The demarkation of the thorax into the three regions is extremely obscure even on the ventral surface and totally lacking on the dorsal, which is partly broken and lying beside the rest of the specimen. Anteriorly the fragment is somewhat broadly rounded and posteriorly irregularly broken. Three similarly segmented appendages—incomplete thoracic legs—and the cavities of origin of two others can be seen, especially under high power with oblique illumination using light blue filter. Two of these legs are on one side of the thorax. One leg is very short and is represented in its extreme basal portion only. It is still attached to the thorax and three distinct segments can be distinguished in it. This appendage measures about 65 microns in length; its basal segment is transverse and about 9 microns long, the second about 40 microns and the third (apparently broken) about 15. Three disarticulated pieces of the other appendage lie beside the thorax. The segments are moderately stout and cylindrical. The third leg is still attached to the thorax on the opposite side and represents only the basal part with the coxa, trochanter and part of femur distinct. The cuticle was apparently finely tuberculated, but shows no traces of hairs or of scales. Spiracles are absent.

The material is most probably a fragment of one of the aberrant Collembolan families, *e.g.*, Produridae, which are devoid of scaly covering; on the body, have the segments of the thorax fused together, short and similar legs and lack spiracles and tracheal system. The Collembola, though apterous and primitive in many respects, are by no means an ancient order, but actually arose from the Protephemeroïd stem of the Pterygogenea (Fig. 10) during the Cretaceous. The oldest fossil Collembolan comes from the Tertiary: 67 species are known from the Baltic amber (Oligocene) and 4 from Copal (Pleistocene). Recent Collembola are the most widely distributed of the terrestrial Arthropods.

Loc. Chamber No. 17, 26 incline, upper level, Pharwala seam, Khewra. Slide No. 41 prepared from rocksalt. *Coll.* B. Sahni, 5 October, 1943.

Subclass	..	Pterygogenea.
Order	..	Coleoptera.
Family	..	Dermestidae.

On slide No. 2 there is an irregular piece of almost structureless, colourless and transparent nearly unchitinised cuticle, about 480 microns long and 360 microns wide, moderately densely and irregularly clothed with numerous



1. Leg of mite. 2. Two basal antennal segments of an Orthorrhaphous Nematocerous Diptera. 3. Gamasid mite; Protonymph. 4. Fragment of thoracic exoskeleton. 5. Fragment of larva of Collembola. 6 & 8. Proximal and distal parts of a tarsal segment of an Orthorrhaphous Nematocerous Diptera. 7. Antenna of a Nematocera. 9. Fragment of antenna of a Homopteran.

long, ferruginous, untufted hairs about 180 microns long and 2 microns thick, each hair rising from a distinct circular area about 5 microns in diameter. Even under the low power of the microscope the hairs appear distinctly spinulose but when magnified about 900 diameters the peculiar barbed structure can be readily seen. The tips of the hairs appear mostly to have been broken.

Considering the fragmentary nature of the material and the absence of spiracles, segmented appendages, surface sculpture or extensive chitinised areas, the only character on which identification can be based is the spinulose and untufted hairs. Although certain Coccids and Aphids among the Homoptera, and the larvae of several other families of Coleoptera (e.g. *Sternocera* of the Buprestidae) and of the Lepidoptera have hairy covering, the material before me does not agree with any of them. The spinulose hairs of the specimen are matched only by those of the larvae of Dermestidae. Recent forms exhibit this character to a very pronounced degree, but even in a Tertiary Dermestid, namely *Dermestes larvalis* Cockerell, from Burmite occurring in Miocene clays in Burma, the spinulose hairs have been figured (Cockerell 1917).

The Coleoptera, the largest order of insects at the present time, arose probably during the Permian, since fossil remains are known from the trias onwards. Although the primitive families of the Adephaga existed even during the Mesozoic Era, the Polyphaga (to which the Dermestidae belong) are essentially a Tertiary group and as can be readily seen from Fig. 10, the order really reached its full development in the early Tertiary. The family Dermestidae first appears during the Middle Tertiary and in any case could not have been much older than the late Cretaceous. In addition to *D. larvalis* Ckll. from the Burmite, 9 other species of Dermestidae are known from the Baltic Amber, 1 from the Upper Oligocene of Salzhausen, 1 from the Upper Miocene of Oeningen and about 7 from the Miocene of Florissant.

Loc. Chamber No. 17, 26 incline, upper level, Pharwala seam, Khewra. Slide No. 2, prepared from Salt and Marl. *Coll.* B. Sahni, 5 October, 1943.

Order	..	..	Diptera.
Family	..	..	Chironomidae.

Chironomus primitivus Mani.

This gnat was found in salt-marl in a band of kallar intercalated between two layers of Rock-salt at Warchha and has already been described by me in an earlier paper (1945). Sahni (1944) has also published two figures of the gnat.

The palpal segments are relatively shorter than in recent species; one of the palpal segments is lying obliquely across the base ventrally on the first abdominal segment. Pronotum narrow as usual but is not so nearly concealed by the mesonotum; propleura much longer than the prosternum. Prescutum of the mesonotum about two-thirds the length of the scutum in the median line. Scutellum half the length of prescutum; its height to length in the ratio of 6:5. Post-scutellum a little longer than scutellum and nearly as high. Halteres as long as post-scutellum. Mesosternum, of which only the median ventral part is visible in the fossil, is relatively smaller than usual and its keeled ventral end is not also so sharply defined; its length to width in the ratio of 9:5. Mesepimeron is marked off from the mesosternum by a very fine obliquely transverse furrow, while in Recent forms this furrow is nearly transverse; its maximum length to maximum width in the ratio of 4:3. Mesopleuron is nearly as long but somewhat narrower than the epimeron. Metapleuron equal to mesopleuron; maximum width above nearly twice the minimum width below.

The relative sizes of the prescutum, scutum, post-scutellum, mesepimeron and mesopleuron compared with those of recent species, indicate less specialised dorsal longitudinal flight muscles. The relatively shorter median ventral lobe of mesosternum and the obliquity of mesosternal mesepimeral suture similarly indicate a more primitive condition for the development of the dorso-ventral flight muscles.

The genus *Chironomus* Meig. is recognised by clearly defined characters and is well represented in the Tertiary and Recent fauna of the world. Of about 1600 existing species of the family described so far 400 belong to the genus *Chironomus*, 70 of which are from India (Kieffer 1906). Recent species of *Chironomus* generally differ in the greater convexity of the mesonotum and the recession of the metanotum into the abdomen than in *C. primitivus*, undoubtedly due to the higher specialisation and greater perfection of the flight muscles. In view of this character I have used the name *Chironomus* sens. latiss. Chironomid species with a relatively more primitive thorax must have long become extinct, as such species are no longer seen at the present day. This conclusion is entirely in agreement with the experience gained elsewhere by study of insect fossils. Genera of insects are generally of long duration, while species appear to be always comparatively much shorter lived. Thus strata of nearly the same or quite the same age often contain insect faunulae in which the species are all distinct. This may be due partly to different ecological condi-

tions and to migrations but more perhaps to the comparatively very rapid evolution and therefore extinction of the insect species. For example the Pleistocene Coleoptera of America described by Scudder (1901) comprise the same genera as we find today in that region, while the species are close to but quite distinct from the Recent ones. It thus happens that Recent genera, to include the Tertiary species, have often to be understood in a broader sense than when used for existing forms. The Diptera are no exception to this. Although the first undoubted remains of the order appear in the Lias (Fig. 10) (they must evidently have been evolving during the Trias), the Diptera are, as is well known, still highly plastic and are rapidly undergoing change.

Loc. A tunnel in Warchha mine. *Coll.* B. Sahni, 14th October 1943.

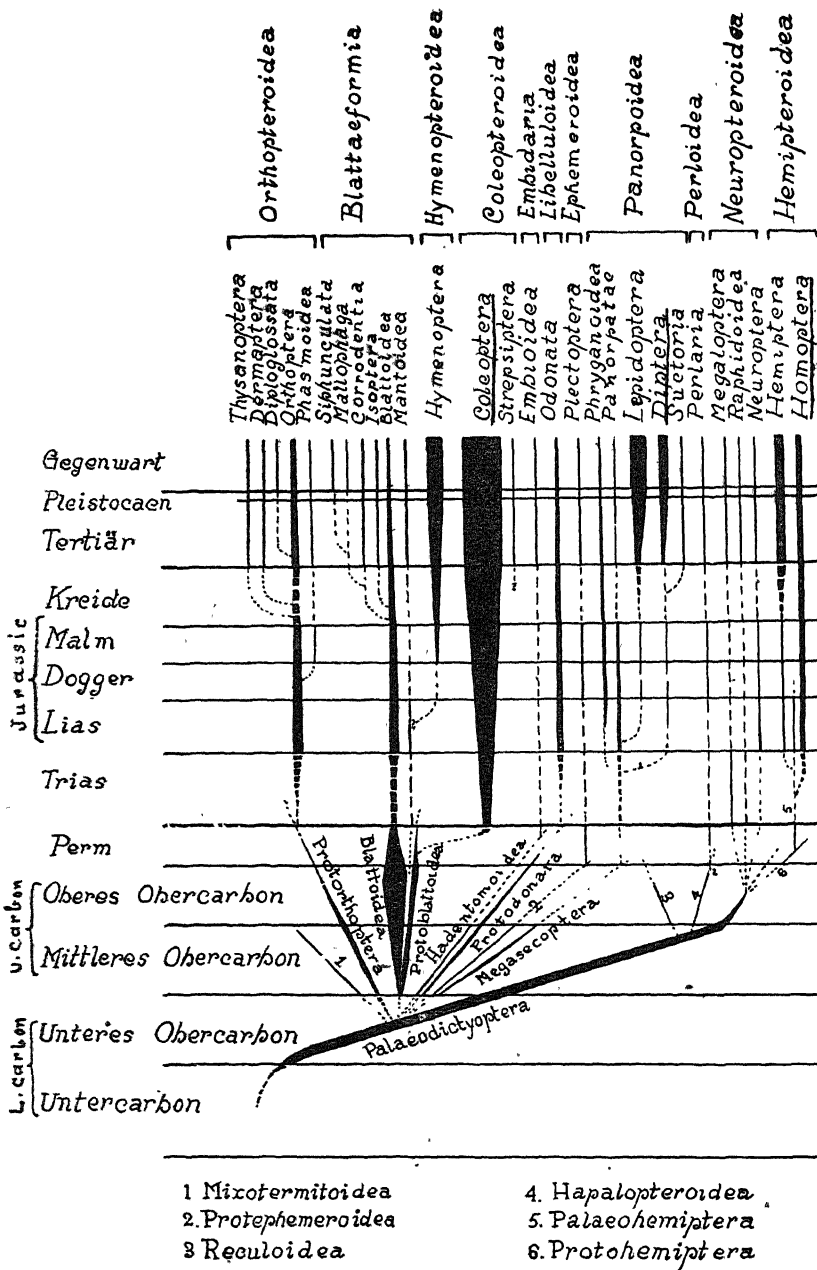
Diptera Incertæ Sedis.

There are three fragments of the chitinous exoskeleton of Orthorrhaphous Nematocerous Diptera, comprising one complete tarsal segment of a leg, the first two antennal segments and some distal antennal segments. It is not possible to say whether these fragments belonged to the same individual, but the chances appear to be against it.

Fragment 1.—The tarsal segment (slide No 47; Figs. 6, 8) may possibly have belonged to a minute gnat or midge of the Chironomidae, Itonididae (=Cecidiomyiidae) or Psychodidae. It was found in a specimen of compact finely laminated dolomite belonging to the lower part of the Saline Series as exposed near Warchha.

It is cylindrical, nearly 225 microns long and 30 microns thick, brown, with the surface sparsely clothed with bluntly pointed, short stumps of hairs. There are two complete hairs (Figs. 6, 8) about 25 microns long on one side at about the basal one-fourth of the segment. The hair is moderately stout basally. At the proximal end of the segment the articulating condylar projection is quite distinct, somewhat obscurely truncated at the tip, nearly 15 microns thick and a little longer and situated a little to one side of the segment exactly as in Recent forms. The articulating distal concavity of the segment is also distinct and is laterally bounded by the lobed expansion of the end of the segment.

Loc. At the confluence of the Jarhanwala and the Jansukh streams about 1 mile north of Warchha. In a compact finely laminated grey dolomite within the lower part of the Saline Series. *Coll.* B. Sahni, 14th October, 1943.



10. Diagrammatic representation of the distribution of Insects in Time. Modified from Handlirsch: Die Fossilen Insekten und Phylogenie der rezenten Formen.

Fragment 2.—The second specimen (slide No. 5; Fig. 2) namely, the first two antennal segments, was found in a specimen of oil shale collected by the Salt Range Excursion party led by Mr. E. R. Gee in November 1944. The segments might have belonged to a midge of the family Itonididae which is characterised by the short scape and the more or less transverse and subglobose pedicel.

The scape is about 290 microns wide and 240 microns long and rather obliquely obconical. It is somewhat obscurely produced apically on the ventral aspect, as is often met with in certain Recent midges. The second segment (pedicel) is however not quite so typical and has probably suffered slight damage. It is distinctly wider than long as in Recent forms, 256 microns wide and 160 microns long and also somewhat wider basally than apically.

Loc. Upper Gypsum stage of the Saline Series in the Nawabi Kas, Makrach. *Coll.* E. R. Gee and party, November 1944.

Fragment 3.—The third fragment (Slide No. 33; Fig. 7), although more complete than the other two, is however far from satisfactory in its preservation. It was prepared by Mr. R. N. Lakhanpal, M.Sc. from a specimen of rocksalt from a borehole at Khewra.

Loc. From the borehole of the Saline Series in the exploratory drift just north of the Bhandar Kas, Khewra. *Coll.* E. R. Gee and party, November 1944.

There are ten cylindrical, moderately slender segments, without stems, sculpture, hairs, setae or scars of hairs or setae or other antennal sensoria usual in the Nematocerous Diptera. This is perhaps due to the fact that the material has undergone considerable damage either before it was buried in the rock or during maceration of the rock in the laboratory. Parts of it show evidence of shrinking and one segment is partially twisted. It is doubled upon itself and one segment in the longer arm of the double is longitudinally split. The reddish-brown colour of some of the segments is evidently that of the safranin or the matrix.

This fragment may have belonged to a Nematocerous fly with slender cylindrical antennal segments, as met with for example, in the families Mycetophilidae, Asphondylariae of the Itonididae etc. I am at present unable to express any further opinion regarding this specimen.

Order Homoptera.

There are two fragmentary chitinous specimens of segmented appendages most probably of Homoptera.

Fragment 1.—In my earlier paper I have already figured and briefly described one of these fragments, which I consider to be a part of the leg of an aphid. I was found in a sample of Salt-and-Marl at Khewra (slides Nos. 19, 20).

Loc. Chamber No. 46, 2nd sub-level North on the 43 incline area, Mayo Salt Mine, Khewra. Surface height 660 feet, distance from mine mouth, 6200 feet. *Coll.* C. Phillips, Feb. 1944. The specimen is registered as P₁ (Phillips 1) in the Sahni Collection of Salt Range rocks.

Fragment 2.—The other segmented appendage is on slide No. 7 (Fig. 9) and was found in a sample of black-and-white banded dolomite from the Warchha gorge. It is perhaps a portion of the antenna of an Aphid or an Aleurodid. The fragment measures about 160 microns long and 80 microns thick. The segments are uniformly thick, cylindrical and comprise the apical part of one and the basal of the other succeeding. There are sparsely scattered scars of setae on both the segments. In one case the base of one of the setae is still intact. The larger of the two fragmentary segments is rather irregularly broken. On the opposite side obscure and fine corrugations of the chitin can be seen; these very probably represent some of the transverse furrows commonly met with on the antennal segments of many Homoptera. An irregular obscure patch on the same side just close to the articulation of the two segments may perhaps represent one of the sensoria.

Though Homopteran fossil remains are known from the Lower Jurassic (Lias), the families Aphididae and Aleurodididae appear very late, in fact first in Old Tertiary beds.

Loc. From an outcrop of contorted and shattered gypsum and dolomite rocks near the stream bed on the left bank of the main Warchha nala below the junction.

Class	..	..	Arachnoidea.
Order	..	..	Acarina.
Family	..	..	Parasitidae.

On slides 20 and 91 are found some ova and protonymphs of free-living Gamasid mites (Fig. 1, 3) obtained respectively (a) from Warchha 14, a dolomite, and (b) from Salt and Marl K5 from Khewra.

The ova measure on the average about 132 microns long and the protonymphs about 212 microns long. The ova appear to have been in an advanced stage of development when they became buried in the rock. Under the high power of the microscope the inner mass of each ovum appears divided into numerous oval reticulated areas, giving the entire ovum the false appearance of a polyembryonic egg. The appendages of all the protonymph are more or less broken and fragmentary. Some of the protonymphs are lying on the sides and other, either dorsally or ventrally. One of the nearly complete legs of a protonymph is shown separately in Fig. 1.

Loc. (a) The main rock of the oil shale outcrop (Sahni, B. 1944, *Proc. Nat. Acad. Sci. Ind.* 14(6). Photo 5). *Coll.* B. Sahni and party. 5 Oct. 1944.

(b) Pillar 47-48, 43 incline, 2nd Sub-level North within the Buggy seam, Mayo Mine, Khewra. *Coll.* B. Sahni and party. 3 Oct. 1944.

Arthropoda Incertae Sedis.

A minute fragment of thin transparent, yellowish-brown chitin of the exoskeleton, with an irregular piece of colourless intersegmental (?) part of the unchitinised integument, apparently belonging to the thorax region of a terrestrial Arthropod is on slide No. 111, together with pieces of membranes and minute shreds of woody tissue obtained from Salt and Marl, K₅.

The chitinous piece measures about 480 microns long and 235 microns wide. It is slightly curled. A few scattered oval bases of broken setae occur on it. Towards one of the longer margins there are transversely parallel rows of very fine shagreening like the scales of fish along the entire length of the piece (shown in part in fig. 4); this shagreening appears to be on the inner surface of the fragment, so that it might represent the rough surface for the attachment of some skeletal muscle.

Loc. Pillar 47-48, 43 incline, 2nd Sub-level North within the Buggy seam, Mayo Mine, Khewra. *Coll.* B. Sahni and party. 3rd Oct. 1944.

ADDENDUM.

(Received 23 February 1946)

Since writing the above, Professor Sahni showed me some further slides of microfossils from salt, marl, dolomite and oil and kerogen shales from the Salt Range. These microfossil animal remains, described below, likewise comprise pieces of membranes, hairs, chitin, etc., which though generically indeterminable, are yet of considerable value. Particular attention should be directed to the hair of the Dermestid larva recovered by Mr. R. N. Lakhanpal

from pinkish marl, with salt in 2" core samples obtained by Mr. Lamba at 229 ft. depth below the South Pharwala Seam, Mayo Salt Mine, Khewra. As already pointed out, the Dermestidae are a Tertiary family of Coleoptera. Fossil species of Dermestids have been described from the Middle Tertiary but no doubt the family had already become differentiated during the Eocene.

Class	..	..	Insecta.
Order	..	..	Coleoptera.
Family	..	..	Dermestidae.

On slide No. 98 (prepared by Mr. R. N. Lakhanpal) there is a spinulose microcheta from the body of a Dermestid larva. It measures about 140 microns long and 5 microns thick at base, light brown, solid, stout basally, somewhat dark brown at the very base, extremely finely spinulose along the entire length.

As is well known, there are two types of hairs on Dermestid larvae: one rather long, very pronouncedly spined and terminated by clavate articulated processes and the other shorter and with spinules. The fossil specimen agrees completely with the latter type of setae of Recent material. Another fragment of a Dermestid larva, described earlier in the paper, was found in salt and marl from the Upper Pharwala Seam.

Locality.—Lamba's material in 2" core samples recovered at 229 ft. depth in bore holes below the South Pharwala Seam, Mayo Salt Mine, Khewra, pinkish marl, with salt.

Arthropoda Incertae Sedis.

A. *Microfossil from pinkish marl with salt.*

Fragment 1.—On slide No. 97 (also prepared by Mr. Lakhanpal) there is a fragment of a brownish, segmented, filiform, cylindrical, hollow, chitinous structure (Fig. 31 of Mr. Lakhanpal's paper), with eight complete subcylindrical segments and a part of the ninth. The segments gradually grow more and more slender and elongated from one end to the other, the thinnest part of the fragment being represented by the broken ninth segment. The thickest segment has a length about one and one-fourth its diameter and the thinnest complete segment (*i.e.*, the eighth) is one one-third the diameter of the thickest. The surface of the segments is quite smooth and is devoid of any setae or scars of setae. The segments articulate with each other directly without an intermediate stem. The total length of the fragment is 170 microns, the maximum diameter 12 microns and minimum 3 microns.

The fragment does not seem to be either a palpus or an antenna. Certain insects have long segmented, gradually reduced terminal fila posteriorly on their abdomen; the specimen may perhaps be a similar structure.

Locality.—Lamba's material in 2" core samples recovered at 229 ft. depth in bore holes below the South Pharwala Seam, Mayo Salt Mine, Khewra.

B. Microfossils from dolomite with saline pellets and white salt in cracks (bituminous).

Fragment 2.—On slide No. 57 (Lakhanpal) there is an irregular piece of colourless, transparent, thin, animal membrane, attached to a short, straight subcylindrical, moderately slender, hollow rod-like structure about 311 microns long. There is in addition an irregularly lacerated piece of chitin (?) lying loose on the membrane. This piece and the rod-shaped structure are deeply stained by safranin used when the rock was dissolved in order to readily pick out the organic particles. On the rod-shaped structure there are three circular clear spots, apparently indicating the roots of branches. The membrane might possibly represent a portion of the wing of an insect and the rod-shaped structure would thus appear to be a part of a ramified venation. The true nature of the material is obscure.

Locality.—Lamba's material in 2" core samples recovered at 125 ft. depth in boreholes below the South Pharwala Seam, Mayo Salt Mine, Khewra.

Fragment 3—On slide No. 56 (Lakhanpal) there is a slender, cylindrical, solid, uniformly thick, irregularly curved "hair-like" structure, somewhat swollen like a hollow sucker at one end and abruptly broken and "frayed" out at the other and deeply stained by safranin. This does not appear to be an arthropodan structure but has some resemblance to the byssus thread of the Pelecypod-Mollusca. The true nature of the specimen is not known.

C. Microfossils from oil shale.

Fragment 4.—On a slide prepared by Professor Sahni there are two minute unidentifiable pieces of organic tissue obtained from the oil shale from Fatehpur Maira Gorge. (Rock specimen S.57, *Coll. B. Sahni*. Oct. 1945).

D. Microfossils from Kerogen Shale.

Fragment 5.—On another slide prepared by Professor Sahni there are several pieces of chitin, membranes and thread-like structures, discovered by him in a thin band of Kerogen shale within the upper part of the Saline Series in the Khewra gorge (Rock specimen S.81, *coll. B. Sahni*. Oct. 1945).

The chitin comprises four semi-transparent, amber-coloured pieces of exoskeleton of an Arthropod. Professor Sahni tells me that these pieces

represent parts of a larger fragment which actually broke on the slide. A camera lucida drawing of the original piece, and some photographs, are reproduced in his paper. Two of the pieces are relatively larger, subequal, subtrapezoid, somewhat convex, with the margins irregularly lacerated; smooth and without any characteristic sculpture. On one of these pieces occur irregularly scattered, long, slender, slightly curved, acute setae or circular scars of the bases of setae; on the other piece there are only two of these.

The largest piece measures about 133 microns long and 88 microns wide. The number of setae on this are as follows: four in a close group submarginally on the irregularly convex margin, two on the side nearer the narrow margin and separated from each other by a distance a little less than the length of a seta; one much longer seta in the middle rather nearer the four-group. There is in addition the basal third of one seta between the group of fours and twos. Length of seta 26-31 microns, thickness about 1 micron; the circular scars of the seta about 7 microns in three cases and 5 microns in diameter in the rest. There is a stout conical brown chitinous spine-like bluntly pointed structure lying loosely in the middle and about 10 microns long and one third as thick at its base. Under high power the chitin appears finely granulose.

The fragments bear some resemblance to the sternite of certain species of *Cimex* (Heteroptera) parasitic on bats.

Fragment 6.—On the same slide there are other unrecognisable animal tissues, one of which is a piece of elongated, membranous, hyaline, finely longitudinally striated structure, broken into two portions still sticking together.

Locality.—A very thin band of Kerogen shale interbedded with the gypsum dolomite of the upper part of the Saline Series, Khewra gorge (Anderson's locality), at a horizon a few feet above the outcrop of Khewra Trap.

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A RECONSIDERATION OF THE NAPPE IN MANDI AND THE PROBABLE AGE OF THE SALT.

By

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(*With one map*)

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1. GENERAL REMARKS.

The origin and age of the rock salt deposits of Mandi are not established facts and, though a number of observations have been made and some views have been expressed by various investigators at different times, the problem has not been studied in any detail so far. The solution, whenever given, by no means appears to be conclusive. This is due partly to the paucity of data that we have on record, and partly to the complexity of the geological structure of this area. Medlicott (1864) believes that "the natural history of the salt is still very obscure". Roy (1933) advocates a Tertiary age for the salt formation more in support of his nappe concept than with the object of proving its age. Pascoe (1921) on the basis of Palmer's and Jameson's (1843) reports also considers the Salt deposit to be of Tertiary age. I have not been able to see Palmer's report. But Medlicott's study of the field evidence appears to be more systematic than that of other investigators, and he, while approaching the problem with an open mind and exercising restraint in reaching his conclusions, is inclined to favour the sedimentary origin of the salt without assigning any age to it.

During the course of a mineral survey which I was conducting in Mandi State in the winter of 1942-43, I had an opportunity of examining the rock salt deposits. Apart from what seems to be a complete inversion of the normal sequence of rocks on the east of the Boundary Fault, the apparently sandwiched position of the salt formation between the Trap on the east and the Dolomite on the west appeared most curious to me. The nature of my work and the time at my disposal did not make geological mapping of the area possible and I have had largely to draw upon Roy's geological map; a relevant portion of this map (Plate 1) has been adapted for the present paper. But from the broad facts that I was able to study during my survey, I feel that the problem calls for a more detailed examination, and that its solution may indirectly provide another clue to the much-debated age of the Salt Range-salt. It is a pity that Roy, who has worked in some detail on the rocks of this area, did not publish his sections which would have considerably simplified the study of their structural relationship.

At first, the inferior position of the salt formation to the trap tempted me to consider the possibility of the salt having been derived from the action of some hypogene intrusive originating from, or having some connection with, the volcanic activity in this region. A similar view was advanced by Middlemiss (1891) for the salt of N. W. Punjab. But a more careful examination would show that a body of salt, seemingly enclosed in rocks which were later folded and over-thrust and moved forwards, would have been completely squeezed out or would have developed strong induration features. I have not been able to notice any such features in the field.

There is no doubt that the salt bed has been subject to some compression and that there is, perhaps, local pinching out at places producing lenticular masses out of what may originally have been one continuous formation. But this might be accounted for by a different explanation in which it is not necessary to assume that the salt bed is a member of the older formations on the east of the Boundary Fault. At least in this case, therefore, the hypogene intrusive view of the origin of the salt appeared untenable.

On the other hand, the infra-trappean position of the salt bed seems to indicate that it is of pre-trappean age unless the overthrust postulated by Roy (1933) includes both the Trap and the Dolomite—both members of the same Permo-Carboniferous group of rocks—in the thrusting and translation.

On the basis of this assumption, the occurrence of vastly older slates—termed Simla Slates and Chail series by Roy—over the younger Trap cannot be accounted for unless a second nappe, which could have brought and left these Slates over the Trap, is considered.

Thus, from the broad facts I am led to believe that there was not one nappe in this region as postulated by Roy in which only the Dolomite was involved, but at least two nappes; that in the former both the Trap and the Dolomite were involved; that the salt-formation was not a part of the older rocks and was not involved in the thrusting; and that the age of the salt formation would be determined by its relations with the over-thrust masses.

We shall now consider the different views advanced and see whether, and how far, the field evidence available supports this and the previous views.

2. PREVIOUS WORK.

Medlicott (1864) considered the possibility of (a) contemporaneous deposition, (b) pseudomorphism, and (c) totally subsequent introduction, and was led to the conclusion that the balance of evidence was in favour of the first mentioned mode of origin of the salt formation.

Warth (1873) who after an examination of these deposits submitted a manuscript report to the Mandi Government, which I was able to read through the courtesy of the Durbar and its officers, has described the rock formations and the salt deposits in some detail, but did not advance any views as to its origin or age, although he remarked on the singular absence of Gypsum from the salt formation.

A. English (1915) considered the salt deposits mainly from the economic and the mining point of view and his manuscript report to the Mandi durbar does not contain any observations on the associated rocks or the possible mode of origin of salt.

McMahon (1882) directed his attention mainly to proving the basaltic nature of the Trap about which some doubts existed in his time. Although the salt-formation is closely associated with the Trap, he did not attempt to study the contact between the two nor defined their relationship. He has not assigned any age to the Trap.

Pascoe (1921) summarising Capt. Palmer's observations writes that according to the latter "the Salt belongs to the same period as the so called Krol limestone of the area", and expresses the opinion that "His (Palmer's) work tends to confirm the view expressed by Sir Henry Hayden in 1904 and by

myself (1912-1921) more recently that the salt and its associated marls are sedimentary deposits belonging to the Sabathu stage of the Nummulitic series." It is difficult to see how Palmer's observations confirm Pascoe's view unless it is assumed that the "Krol limestone" is of Tertiary age. As we shall see presently there are structural considerations which make the Tertiary age of the Krol limestone untenable. Pascoe's opinion just referred to is that the association of the bituminous occurrence, described by Jameson (1843) and later confirmed by Palmer, "with gypsum, salt marl, and rock salt, and its continuity with, but definite separation from the Tertiary sandstones, have many points of significance, and support the view that we have here a junction between Sabathu and Murree beds."

Roy (1933) puts forward the view that owing to overthrusting of rocks of this region the Krol dolomite masses occur as mere "Klippen" and that "the rock salt is associated with Lower Siwalik sandstone with stringers of coal, next to the rock salt (Lochan) to the east of the dolomite at Guma, not only indicates that the salt is of Tertiary age but also that the Tertiaries (Upper Siwalik conglomerate) west of the dolomite, are continuous with those (Lower Siwalik Sandstone) to the east of the dolomite." It may, however, be stated here that he applies this observation to the proving of his nappe concept and, therefore, this somewhat casual observation is only incidental to his main enquiry which is not concerned with the origin or age of the salt formation.

3. TOPOGRAPHICAL FEATURES.

Mandi State ($76^{\circ}40' : 31^{\circ}23'$ and $77^{\circ}22' : 32^{\circ}4'$) lies north-west of Simla, covering an area of about 1,200 square miles most of which is mountainous country. Two main parallel ridges, of which the eastern and higher is the Ghoghar-ki-Dhar, run roughly north to south, and trisect the State. The ranges in this area conform to the general N.W.-S.E. trend of the ranges running up from Sirmoor State through Simla to Mandi and beyond, and indeed, form a topographical unit with them. In a general way they have been subject to the same orogenic forces which were operative in and around the Simla region of the Himalayas.

The Beas river, which is the most prominent drainage line in Mandi, makes its entrance at about the middle of the eastern boundary from where it runs almost east to west until it reaches the town of Mandi. Here it takes a sudden turn and flows northwards for a few miles and then adopts a north-westerly course till it makes its exit at the western boundary to enter the Kangra district.

The main Jogindarnagar-Mandi road runs north-to-south between these two towns along the western flanks of the Ghoghar-ki-Dhar, almost along the zone of the Main Boundary Fault and the faulted contact of the Palaeozoic rocks on the east and the Tertiary rocks on the west.

4. SALIENT GEOLOGICAL FEATURES OF THE ROCK SALT AREAS.

Almost the most striking feature of the geology of this region are the great stratigraphical gaps which separate the rocks that comprise the present succession east of the main boundary. All these beds, in general, have easterly or north-easterly dips pointing in the direction from which the movements seem to have come. Starting from one of a series of faults that constitute the main boundary fault, and following the outcrops eastwards, one comes across—broadly speaking, since there are local modifications—the outcrop of dolomite referred to by Roy (2) as Krol Dolomite, overlain by Lochan* which contains the salt bed, and which, in its turn, is overlain by trap succeeded by a broad outcrop of slates which extend eastwards beyond the boundary of the State.

West of the fault are the Kasaulis, followed by Siwalik formations which include the Siwalik boulder bed. The abrupt contact between the Palaeozoic and Tertiary rocks on either side of the fault is well exposed in many places.

At a number of places the Dolomite is seen to be in contact with the Trap and appears, more or less, to overlie the Lochan. At others, the Dolomite appears to underlie the Lochan. The general stratigraphical succession, local variations and modifications excepted, can be observed right from near Jogindarnagar in the north to Mandi in the south and beyond. However these rocks might be related to one another structurally, they invariably display a close association and present, with the exception of Lochan, nearly uniform development almost over the whole length of the outcrops. The normal succession may be summarised in the following manner:—

7. Upper Siwalik Conglomerate.
6. Middle Siwalik Sandstone.
5. Lower Siwalik Sandstone.
- FAULT,
4. Lochan.
3. Dolomite.
2. Trap.
1. Slate.

*Lochan: (Lukhan of Warth), presumably a corruption of Lunkhan (Lun-Salt, Khan-mine):

(1) *Slate*.—The slates have been referred to as Simla Slates and Chail Series by Roy (1933). They have a wide distribution here and cover a large part of the territory east of the main boundary forming the main bulk of the Ghoghar-ki-Dhar. Their cleavage is very well developed and laminae $\frac{1}{8}$ inch thick can be parted. The slates, dark grey or greyish-green in colour, and often very ferruginous, are folded into a series of anticlinal and synclinal folds with a N.-S. orientation of their axes.

(2) *Trap*.—McMahon (1882) finds the Trap of Mandi to be basaltic. It shows a bluish green colour on fresh surfaces which is comparable with the colour of the Panjal Trap of Kashmir, but the amygdales are not much developed. Possibly, they have been obliterated by later compression. The Trap presents no evidence to show that it is of Tertiary age. Wherever examined, it is found to be severely crushed and broken up into sizes varying from 8 ft.—10 ft. boulders to quite small angular fragments which form thick scree slopes obscuring junctions and contacts between various formations.

(3) *Dolomite*.—The Dolomite is a hard compact rock, at times massive and at others bedded. It is fine-grained, often metamorphosed and pink to grey or bluish grey in colour. It exhibits a faulted contact with sandstones (Kasaulis of Roy) which is particularly well-exposed at Drang and Maigel. Everywhere it shows unconformable junctions with the juxtaposed rocks.

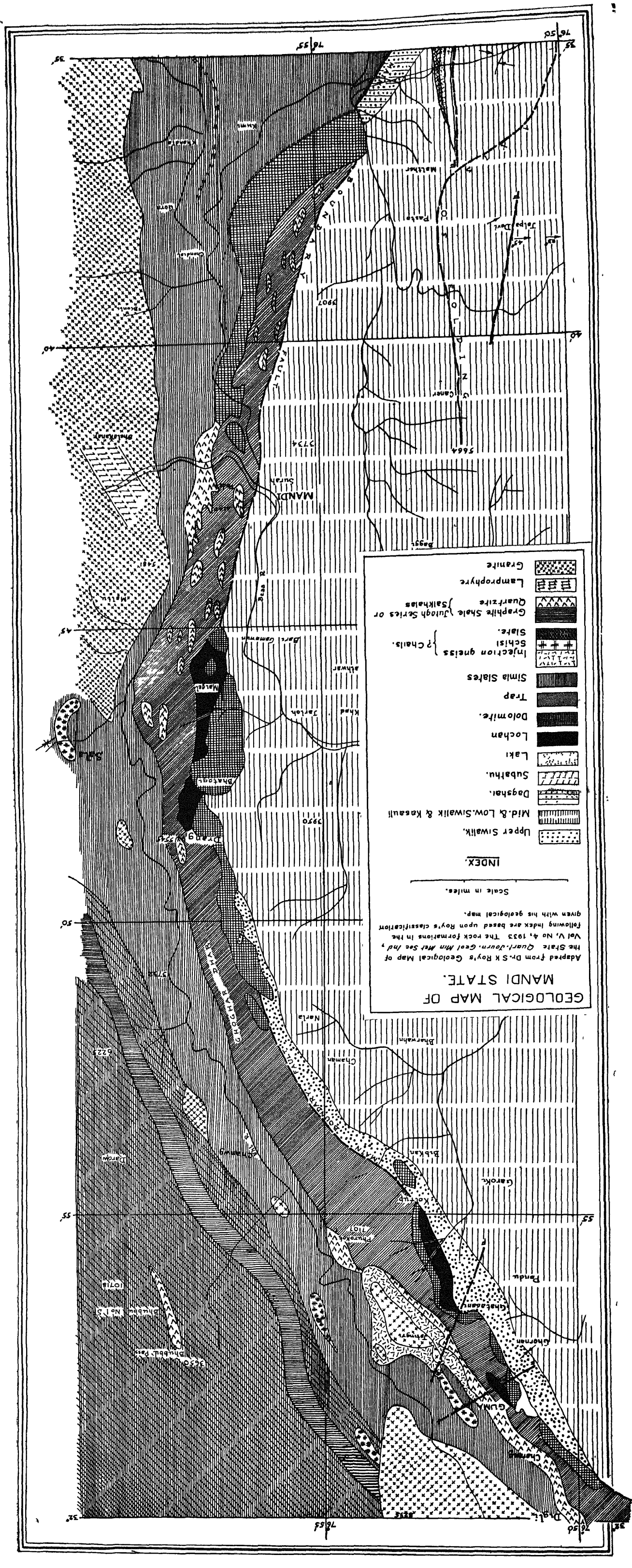
At Guma, at the inner curve of the road just below the mine, it seems to lie on the sandstones probably of Kasauli age and occurs to the west of the Lochan outcrop which also it might be overlying. The western edge of the Dolomite is in contact with the conglomerate bed of Upper Siwalik age.

At Ghatasani, it appears over the Trap and the Lochan, but at Drang and Maigel, again, it occurs to the west of the Lochan and shows a faulted contact with the Kasauli sandstone.

South of Maigel, it occurs both over the Trap on the east and the Lochan and sandstone on the west.

South of Mandi it occurs on the eastern flank of the Trap outcrop which, presumably, it overlies.

(4) *Lochan*.—The Lochan formation presents the appearance of a rotten rock from which most of the salt seems to have been leached out. Medlicott (1864) proposed the term "Salt Gossan" for it. Dr. Warth (1873) described his experiment in which he dissolved a maund of rock salt and found the insoluble



- INDEX.**
- Granite
 - Lamprophyre
 - Quartzite
 - Graphite Shale, Juloth Series or Salkhalas
 - Schist
 - Injection gneiss } Chails.
 - Simla Slates
 - Trap
 - Dolomite.
 - Lochan
 - Laki
 - Subathu.
 - Dagshai.
 - Mid. & Low. Siwalk & Kasauli
 - Upper Siwalk.

Adapted from Dr. S. K. Roy's Geological Map of the State. Journ. Journ. Geol. Min. Nat. Sci. Ind., Vol. V, No. 4, 1933. The rock formations in the following index are based upon Roy's classification given with his geological map.

Scale in miles.

MANDI STATE.

residue to resemble the Lochan. This formation has a white to pink colour and is chiefly arenaceous though mixed up with some clayey material. It is quite soft to break and a lump crumbles readily under a soft blow with the hammer. At Drang it forms almost vertical cliffs which are more than 200 ft. high. Lochan is the home of salt and carries an impure salt bed at its base varying in thickness from 70 to 100 ft. Some old workmen, who have been employed in these mines for a very long time, told me that they have made chambers in the body of the salt 60-90 ft. deep with about 20 ft. of salt left in the roof and yet, at no time, have they struck the substratum of salt. After discounting the possible exaggeration in these statements, a safe 70-80 feet may be considered as the probable thickness of salt. At Guma, at the time of my visit, I myself saw a chamber about 40 ft. deep with about 15-20 feet of salt in the roof. Parker (1926) reports 76 feet of salt at a depth of $1\frac{1}{2}$ feet in a bore-hole he sunk at Drang, and further records in his bore-hole log that the last $11\frac{1}{2}$ feet of this thickness consist of a band of pure white salt. Usually, the salt is impure and purple in colour with clean, white, and sometimes small almost translucent lenses in its mass.

Siwalik Rocks.—Immediately to the west of the Dolomite or Lochan, and in contact with either, along the fault zone, occur rocks of Siwalik age ranging upwards from the equivalents of the Murrees. The Lower Tertiary rocks are nowhere exposed except for a small band of nummulitic limestone and sandstones, etc., of Eocene age south of Galma near the Mandi-Suket border. The sandstone in contact with the Dolomite in all the places is the same and has been referred to as the Kasauli sandstone by Roy. It is of an earthly brown colour, somewhat coarse to touch, and not so hard as the Dagshais, but I have not found it to contain any bands of red clay. In the absence of fossils and pending more detailed examination it would be somewhat difficult to refer it with any certainty to either the Dagshais or the Kasaulis. But it would suffice for our present purpose to regard it as an equivalent of the Murrees.

5. EXPOSURES AND STRUCTURE OF ROCKS IN THE SALT AREAS.

It will now be useful to examine briefly the manner in which the rocks are exposed in the different salt areas of Mandi and to note their relations with one another. The best exposures are seen at Maigel, Drang, Ghatasani and Guma.

Maigel.—Five miles north of Mandi town, at Maigel, are two small valleys, almost parallel to the strike of the rocks and to the strike of the range, bounded by nearly vertical cliffs, through which flow small streams. In the larger and

eastern valley, facing north towards the head of the stream, the left cliff is found to be composed almost wholly of Lochan. Some Dolomite occurs on the top of the cliff but the main exposure is outside this valley to the west of the Lochan and to the south of it along the curve of the road near the entrance to the valley. The Dolomite here is much broken up into angular elongated splintery fragments and the talus derived from it covers the slopes so that junctions are not seen clearly. On the right in the same valley, the bulk of the cliff is made up of Dolomite with a bed of finely banded, pinkish and purple calcareous rock, mixed up with arenaceous material at its bottom. There are pockets of a white material, presumably derived from the weathering of this bed and locally known as *Mokol*, which is used for whitewashing. This banded rock may be a facies of the Blainis. I found on the bed of this valley some large rounded and hard blocks of a crush-breccia composed of angular and generally rectangular fragments of this rock so strongly cemented together that the hammer failed to break them. Northwards, towards the head of the valley, the green Trap capping the higher slopes is seen to overlie the Lochan, their junction in vertical section showing an irregular zig-zag line.

In some places, at the bottom of both the valleys, are seen outcrops of a brownish sandstone resembling that of Drang and Guma.

Drang.—At Drang, about 7 miles north of Maigel, is another large outcrop of Lochan occurring in a sort of an elongated amphitheatre formed by Lochan cliffs on the east and by the large Dolomite outcrops on the west. In this amphitheatre, almost along the whole length of the cliffs on the east, the junction between the Lochan and the overlying Trap is clearly exposed and presents the same irregular appearance which we noticed at Maigel. On the west, the Dolomite clearly seems to dip under the Lochan, and its contact with the Kasauli sandstone at the entrance to the stream running between the Drang and Tokri villages, is a faulted one.

Adits driven into the cliff at the northern side of the amphitheatre have yielded large quantities of salt but owing to frequent slips and consequent danger to the workmen they have been abandoned and have since been covered up by falls from above. The floor of the amphitheatre is covered with a heterogeneous debris in all stages of comminution but the salt, which is now won from pits sunk into the floor, is met within a few feet of the surface.

Ghatasani.—There is no record of an attempt to find and work the salt at Ghatasani, and the general belief of the local people is that no salt occurs

there. The Lochan is again exposed here. The Dolomite outcrop seems to partly overlie the Lochan and partly the Trap which is a useful evidence in the explanation of the nappe. But of all the Lochan outcrops in Mandi and in spite of a fairly good exposure of it, Ghatasani has received the least attention. *Guma.*—Compared to the foregoing localities, the conditions at Guma are a little more complicated. Here there is only a very small exposure of Lochan on the spur south of the Luni Nal where the salt is won by means of an adit. Just above the mine is an almost vertical cliff, composed of Trap, at the foot of which lie large boulders of the same rock. At the inner curve of the main road, from which the mine is approached, is a small exposure of a brownish sandstone resembling the sandstone of Drang and Maigel in all respects. Overlying this and also probably the Lochan is the Dolomite which forms the spur on which the village of Guma is situated. The contact between the Dolomite and Lochan is not clear owing to vegetation and debris, which cover it, but the Dolomite in disconnected exposures seems to overlie the sandstone, the Lochan and the Trap.

The spur north of the Luni Nal is composed almost entirely of Trap which comes down to the level of the Lochan in the southern spur. The Dolomite is not seen on the outer edge of this spur at road level and the talus of trap covers the slopes, although on the other spur the Dolomite is well-exposed along the road. A quartzite band runs in the Trap to the head of the Luni Nal where it is lost in the debris and does not reappear on the southern spur; possibly it occurs at a much higher level on this side.

Thus, the occurrence of Trap in the northern spur at the level of the Lochan in the southern would indicate a dip fault, running transversely to the main boundary fault and caused by a rupture in the forward travelling fold in the direction of movement which probably resulted in a rotational effect on the northern side throwing the Dolomite further westward where it may be found after some search.

6. DOLOMITE: A KEY TO THE GEOLOGICAL STRUCTURE OF THE AREA.

For purposes of this argument we have adopted the Krol age assigned by Roy to the Dolomite occurrences of Mandi and have accepted his view that it is not *in situ* but owes its present position to an overthrust and translation. But other views have been expressed by other writers and the final judgment on the structure of this area will depend essentially upon the determination of the true stratigraphical position and age of this Dolomite. In other words, we might regard the Dolomite as a key to the geological structure of the salt area.

It might be admitted here that the views expressed by various writers in this regard are somewhat premature and are generally based on insufficient data and coincidental resemblances with some rocks of the Salt Range areas. In the absence of any detailed mapping, the true structure has not been worked out, and therefore, it is almost impossible to be definite about the age of this Dolomite.

According to Medlicott (1864), "the salt occurs very close to but well inside the main boundary, among the limestones, sandstones, and slates which I have supposed to be the same as Krol rocks and which are here much complicated by trappean intrusions."

Pascoe (1912-1921), on the other hand, records that "abundant trappean intrusions are described in the neighbourhood of Mandi salt beds in the Kangra district;" and is of the opinion that "these as well as the salt beds themselves are very possibly of Nummulitic age. Nummulitic traps may quite likely be found in other parts of the Punjab oil-belt."

Again he writes, "The Tertiary age of the Salt Range salt is interestingly supported by the Mandi salt deposits in the Kangra district. The lamination in the deposits proves their sedimentary origin but their age is not certain and there is reason to conclude that Theobald was right in assigning them to the Nummulitics of which they probably belong to the upper stage. A highly gypseous marl, of various tint, bearing a strong resemblance to the red marl at Kalabagh and containing a 'bed of bituminous marl slate' accompanies the salt. The area is disturbed and there is abundant intrusion of Trap.... There seems little doubt that the beds are Subathu and their resemblance in character and position to the Salt Range deposits is strikingly close."

On the other hand, Palmer, as quoted by Pascoe (1921), "concludes that the salt belongs to the same period as the so-called Krol limestones of this area."

Roy also advocates a Tertiary age for the salt but accounts for it differently. According to him the salt forms a part of the Tertiary succession in which the Lower Siwalik sandstone, occurring on the west of the Lochan, is continuous with the Upper Siwaliks, with the inference that the Dolomite is more or less superimposed on all or some of these formations.

Thus, we have three main concepts before us. One concept assigns to the salt and the Trap a Tertiary age without taking into consideration the Dolomite occurrence although admitting, at one place, doubt regarding its age.

The second concept regards the salt as being of the same age as the Dolomite. The third, while admitting the Tertiary age of the salt, assigns the Krol age to the Dolomite and accounts for its present position through a nappe.

It is difficult to see how the Tertiary age of the Trap was arrived at and what rocks in the field are actually referred to when speaking of 'gypseous marl' and 'bituminous marl slate.' However, if the first of these concepts is accepted, it would necessitate the assumption that the Dolomite also is of Tertiary age. But, then, the relationship between the Dolomite and other rocks of the area, already described, would become difficult of explanation. If, on the other hand, the second concept is accepted, then either the Dolomite will have to be assigned a Tertiary age or, the salt formation the Krol or whatever age to which the Dolomite may ultimately be found to belong.

In view of these difficulties, the nappe concept provides a safe working hypothesis which can be proved or disproved by more detailed field work. Considering that Mandi State only forms a more northerly extension of the Nahan-Simla nappe region, the Mandi nappe hypothesis may have more in it than appears at first sight and may reasonably be accepted as a starting point in these investigations.

7. ROY'S HYPOTHESIS.

From a number of field data, Roy (1933) concludes that the present situation and relationship of rocks in the Mandi Salt area is due to a nappe. The main argument in support of his hypothesis, in his own words, is that "the dolomite occurs unconformably related to the underlying rocks which at times are either slate or trap belonging to the metamorphic series, or, at other times, the underlying rock is either Rock Salt, or Kasauli, Lower Siwalik, or Middle Siwalik sandstones of various Tertiary ages." He assumes that the Dolomite alone was folded over, and overthrust as a sheet to its present position where it lies as a rootless mass. According to him, the occurrence in the body of the rock salt of pebbles of Dolomite, serpentine, slate, trap, etc., indicate that the overthrust came about before the drying up of the gulf in which the rock salt was precipitated. He goes on to compare the Dolomite occurrence of Mandi with that of Kulu and thinks that "they are the same," and correlates them by assuming that "the Kulu dolomite must have been carried to the centre of Mandi (which, by the way, is a distance of about 12 miles as the crow flies) from their 'Wurzelregion' (root-zone) in Kulu by tectonic forces Thus, he concludes, "there had been a 'Nappe' type of highly recumbent fold of the dolomite." The Mandi Dolomite, according to him, belongs to the

"Stirn Zone" while the intermediate middle zone has been denuded away. "From the nature of the outcrops of the Stirn Zone and on account of its having the Wurzel zone on the other side (East) of the Mandi granite, the dolomite Nappe is of the nature of a 'Klippen Decke'".

8. DISCUSSION OF THE PROBLEM.

All these observations lead us to a two-fold enquiry. Are we to regard the Trap, the Dolomite, and the Salt formation, as belonging to the Tertiary age? If not, then does Roy's nappe hypothesis, in its present form, sufficiently explain the abnormal juxtaposition of all the rocks in this area?

The most curious fact which makes the acceptance of the first view difficult is the existence of the Dolomite over the Kasaulis, over the Lochan, and over the Trap. Were the Dolomite a normal member of the Tertiary succession of rocks, it should be found almost in the same position everywhere. It should always be found with the younger or older Tertiary rocks and not overlying the trap or the Trap-Lochan junction. But actual field observations show that it lies over them. As seen at Guma and Ghatasani the salt formation occurs east of and next to the Kasaulis and Siwaliks which are roughly equivalents of the upper Murrees and the Dolomite occurs over the Trap Lochan contact. Similarly, south of Mandi, the Dolomite occurs on the eastern margin of the Trap and upon it.

Now the Murrees represent a period of general silting up of the gulf and desiccation. As such it would be quite in conformity with the gulf conditions obtaining at that period to expect the formation of a salt deposit. But there is no evidence to show that the Trap belongs to this or slightly earlier or later age. Its contact with the Lochan shows no more than that each was pushed into the other under some pressure. Nor do the contacts between the Trap and the Slates, or between the Trap and the dolomite show zones of alteration so characteristic of igneous intrusives or extrusives. It is not necessary to assume, as Roy has done, that the overthrust came about before the drying up of the gulf to account for the inclusions of Trap and Dolomite pebbles, etc., in the salt. This could have been, as we shall see presently, a purely subsequent operation.

Of course, the assumption that the Trap, Lochan, and Dolomite form one faulted sequence with the Kasaulis might simplify the undetermined structure but it does not meet the test of field evidence. Then there is the superposition of Slates on the Trap which this assumption cannot explain. On the whole, the

weight of evidence is against the acceptance of this view and some other agency would have to be invoked for an explanation of the present structure of the area.

If, however, the Dolomite alone has been overfolded and overthrust, and pushed forward to its present position from its roots in Kulu as suggested by Roy, the general occurrence of the Trap over the Lochan and its appearance at the northern spur of the Luni Nal at the level of the rock salt formation, with complete absence of the Dolomite on this spur in continuation of the Dolomite at the opposite spur, cannot be explained easily. It would be useful to recollect in this connection that the Dolomite is younger than the Trap (*Krishnan* 1943) in the Permo-Carboniferous sequence. If the Dolomite and Trap both are of Permo-Carboniferous age, the probability is that both these formations were involved in the nappe till they were finally left at their present position over the faulted Lower Tertiary and Middle Tertiary rocks. This would explain the existence of the Dolomite to the west of the Lochan on the Kasaulis, on the Lochan and on the Trap which itself overlies the Lochan. The present outcrops of the Dolomite are considered as mere remnants of the eroded body of this rock which formed the back and the brow of the nappe.

This would also explain the presence of the Trap at the level of the rock salt in the Luni Nal at Guma where the travelling sheet was ruptured in the direction of movement allowing the northern block to move forward and roll over to give to the locality its present structure.

But if this view be correct, then one would seek the root of the nappe not in Kulu as Roy has done, but further north-eastwards in the main body of the Permo-Carboniferous rocks extending in a line from south of Kargil to north of Gangotri. The occurrence of Dolomite in Kulu recorded by Roy, if it is referable to the Mandi Dolomite, would then, perhaps, appear to form a "window" in the Slates belonging to Purana or older rock systems, a view which needs confirmation.

The Slates which are from all appearances very much older than the Trap, are found to overlie the latter in the Mandi salt area, and the intervening formations are missing. This stratigraphical feature cannot be explained by considering simple fractures, faults or overfolds without taking into account some amount of translation which alone could give rise to such a succession as we see in Mandi today. On reference to the Geological Map of India, scale 1 inch=96 miles (*Wadia* 1939), it will be seen that the band of Triassic rocks, running from northwest of Kargil to southeast of Spiti, is flanked on both sides

by comparatively narrow but elongated outcrops of Permian-Carboniferous rocks which, at least along the south-eastern margin, are flanked continuously by rocks of Purana age. It is here probably that we shall have to seek the solution of the nappe postulate and it may be that the original folds were formed in this region and were subsequently overfolded and overthrust southwestwards. It is conceivable that following the first thrust movement which brought the Trap and Dolomite into Mandi and left them there as exotic blocks, there was a second thrust which over-riding the first brought and left the Slates over the Dolomite-Trap thrust. Roy has not considered this aspect of the question nor has he made any observations on the position or contact relations between the Slates and the Trap. Possibly, the relation between the Slate formations and the Trap-Dolomite thrust is one of imbrication. I have not found the Dolomite to lie over the Slates as recorded by Roy.

Broadly speaking, the whole mass of rocks comprising the Slates, the Trap, and the Dolomite seems to over-ride the faulted and overthrust Tertiary rocks in the manner of exotic blocks without any apparent connection with them. Towards the southern extremity of the State, near the village of Galma, where these Palaeozoic and older rocks do not occur, the Nummulitic limestone is exposed along with other Eocene rocks. This circumstance also lends support to the foregoing conclusion that the Nummulitics and other Eocene rocks are exposed only where they are not covered by large rootless masses of older rocks. If these latter rocks had any stratigraphical connection with the Tertiary succession one would expect some outcrops of them where the Tertiaries are most developed. But such outcrops are never seen.

The occurrence of the salt formation, between the Trap on the one hand and the Dolomite on the other, under the circumstances, would not therefore seem to be so curious. Medlicott's observation (1864) that "the salt occurs very close to but well inside the main boundary, among the limestones, sandstones, slates", etc., can be explained by the presence of the Siwalik overthrust which separated the Lower Siwaliks from the Upper Siwaliks. The Lochan is exposed only where denudation has carved out a depression sufficiently deep to reach it. Hardly any indurated features are noticed in it although lamination, pointing to its sedimentary origin as observed by previous investigators, is present. If the Lochan were intimately involved in the folding as a normal member of the folded and overthrust rocks, it could not have maintained such a simple relation with Trap-Dolomite occurrences here. The relation of the Trap and Lochan along the contact is an irregular plane, which in section looks

like small tongues of each passing into the other, showing that both have been forced against each other under pressure. But the moving mass of Dolomite must have been crushed to fragments of various sizes at the brow of the fold and at its base and the pressure exerted by this mass could have easily driven these fragments, noted by different observers, into the plastic body of the salt.

To a certain extent, Lochan seems to have been forced up under the Trap-Dolomite mass. Under the tangential compressive stresses resulting from the orogenic movements, in addition to the huge vertical pressures, the Lochan must have been subject to some amount of squeezing within the Murree sediments when the over-riding mass came on top of it. This may have resulted in the Lochan being pushed up and, so to speak, being forced into the underside of the Trap. This possibility is further borne out by the observation that the Lochan does not show any such contact with the Dolomite. Naturally, this could not have been expected if the Dolomite, as has been assumed by the present writer, lay above the trap on the back and brow of the nappe.

It is not difficult to visualize the picture. At first the Trap-Dolomite nappe comes moving forward till it stops at its present position in Mandi over the Eocene-Murree sediments. Following this, the Slates are overfolded, raised, overthrust, and pushed along over and on to the back of the first nappe. During these operations the Dolomite is crushed at the brow of the nappe and the Trap within its body. The Slates overriding the first nappe must have crushed and broken down the Dolomite on its back which may perhaps exist under the Slates. Denuding agencies which have been operating all this while continue carving the topography of the region till disconnected Dolomite blocks are left sometimes over the Trap, at others over the Lochan, and at still others over the Tertiary sandstones. Sometimes they may be seen to overlie two or more of these rocks simultaneously. The carving proceeds till streams and hollows and valleys become deep enough to expose the Lochan at the base of the trap.

9. CONCLUSIONS.

In a general way the hypothesis advanced above would seem to fit in with the observed facts and to explain certain features which could not be explained by analogies with an area the geology of which is no less complex and the solution no less simple. I do not find sufficient field evidence to support the view that the Mandi Trap and the "Krol Dolomite" are of Tertiary age or that the Lochan is of Krol age. Nor do the observed relations of Trap,

Lochan, Dolomite and the Tertiary sandstones indicate that the Dolomite alone was involved in the nappe, and the Kulu occurrence of Dolomite, if it is the same as that of Mandi, hardly seems to be the root of the nappe. It might be instructive to seek it in the Kargil-Gangotri zone of Palaeozoic and older rocks. From all appearances, what seems more likely is that not one but two nappe movements occurred: one, in which the Trap and Dolomite suffered translation, and the other, in which the Slates were pushed over the back of the first nappe. Roy's hypothesis, as it stands at present, hardly seems to explain all the observed facts and anomalies.

But, as I have already stated, the views that have been discussed in the foregoing pages remain to be tested by more detailed field evidence than has so far been collected. No mylonitic rocks or fragments are seen in this region. It is possible that they have been obscured or removed by denudation. Such rocks have not been recorded in the other nappe regions of the Himalayas. Within the limitations of our present knowledge of the area, all indications appear to point to nappes having been operative in this region in the same manner as in its south-eastern continuation forming the Nahan-Simla belt (*West* 1939) and the northwesterly continuation forming the Kashmir Himalayas (*Wadia* 1931).

The present hypothesis is in no way in conflict with the Tertiary age of the salt postulated by Pascoe. Indeed, it supports it and explains why salt here appears sandwiched between the older rocks. The only difference of opinion that exists is with regard to the age of the Dolomite and the Trap.

It is possible that micro-palaeontology may throw some light on the age of Mandi rocks, particularly on that of rock salt. In fact, I had received a request from Professor B. Sahni for samples of rock salt of the area, which to my great regret and disappointment I could not eventually despatch owing to difficulties in booking them by railway. After the microfossils that Professor Sahni (1944, 1945) discovered in the Salt Range salt, it is quite reasonable to expect some such remains from the Mandi rock salt as well. But, it seems doubtful whether the metamorphosed dolomite will yield any fossils which may help in the determination of its age.

10. POSTSCRIPT.

I must record here my gratitude to Mr. D. N. Wadia, Mineralogical Adviser to the Government of India, for having found time amidst his many pressing engagements to read the manuscript and for giving me the benefit

of his comments. I am further grateful to him for a note he gave me on the subject which I reproduce below with his permission.

"I am in general agreement with the main conclusions of this paper. There is nothing unusual in the structure or disposition of the Mandi nappe front. It is the south-east continuation of the *Murree* and *Panjal* thrusts of the Kashmir Himalayas, disclosing stratigraphic relations of Eocene and Permo-Trias on a plan closely similar to that described in the sections in my Syntaxis paper (*Records G. S. I. Vol. LXV, Part II*, 1931). West has shown an identical structure in the Simla area to the south-east of Mandi.

"The Krols in this area take the place of the Panjal Volcanic series of the north-west and the usual Nummulitic facies of the Eocene is overridden and locally replaced by only its elusive members (the Salt Marl-Gypsum stage of the Kohat and the Salt Range Eocene) squirted out into any available space or a plane of weakness. On this account they occupy erratic and apparently anomalous stratigraphic positions in the overthrust mass. The Mandi salt, therefore, must exhibit mechanical contacts on all sides and we cannot judge its age by its observed stratigraphic relations with Siwaliks, Eocene, Krols or with the Puranas."

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SOME TECTONIC ASPECTS OF THE PROBLEM*.

(Age of the Saline Series in the Punjab Salt Range)

By

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(*With four figures*)

(Received 7 December 1945)

INTRODUCTION.

Before the structural interpretation of any complicated geological feature can safely be attempted, it is desirable that the stratigraphical position of the component rocks should be firmly established. There are however some exceptions to this rule, especially in areas where depositional contacts are obscure and fossil control is absent or unsatisfactory. In such cases a careful analysis of the structural position of a problematical formation may often indicate its probable stratigraphical position and thus substantiate or weaken conclusions based on other considerations.

With regard to our particular problem, the Cambrian or Eocene age of the Punjab Saline Series, it may be argued that the local structures can satisfactorily be interpreted on either assumption. That is so, and it is easy enough to draw a section through any particular locality along the front of the Salt Range, taking the salt either as Cambrian or as Eocene. The problem assumes a totally different aspect, however, when we attempt to construct sections on a wider base, both horizontally and vertically, and to interpret the structure of the Salt Range as a whole in conjunction with the regional tectonics of this portion of the Himalayan foreland.

A thorough discussion of the great tectonic trends of the north-west Punjab would fill a volume and would, moreover, be premature, as our knowledge of many of the crucial areas is still insufficient. I confine myself therefore to some of the tectonic features which are directly connected with the Saline Series and may help to form an opinion about its age.

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ASSUMED CAMBRIAN AGE OF THE SALINE SERIES.

On the assumption of a Cambrian or pre-Cambrian age of the Saline Series the structural interpretation of the Salt Range presents no practical or theoretical difficulties. Various opinions have been advanced which may be classed into the following 3 main categories:

(a) The Salt Range may be considered a *normal anticlinorium* which roots in the crystalline basement, though the surface phenomena need not necessarily be a harmonic reflection of the deep-seated folds which may be much simpler. This view was held by the first writers on the Salt Range and is presumably still held by many who have not expressed a contrary opinion.

(b) The Salt Range can be looked upon as a *sheared fold-complex* ("Abscherungs-Struktur") of the Jura Mountain type which affects only the sequence above the highly incompetent Saline Series and does not, or does only in minor degree, involve the basement below this horizon. This conception is based on the assumption that the weight of the high Himalayan structures in the north has exerted a tremendous southward directed pressure on the foreland which resulted in the forward gliding on a large scale of the whole sedimentary cover above the Cambrian shear-horizon.

On account of the striking resemblance between the sections: Swiss Alps—Swiss Molasse—Swiss Jura and Hazara Himalayas—Potwar—Salt Range I have always been a strong advocate of this gliding theory to which G. de P. Cotter (1933) and E. R. Gee (1934) felt also inclined. I have however modified my opinion somewhat with regard to the hypothetical structure of the basement below the gliding horizon. My former conception that the under-ground has stayed rigid or become only gently warped seems now less attractive, because it would imply a passive southward movement not only of the Salt Range but also of the whole deep Potwar Basin, and I feel now more inclined to believe that the basement became shortened to an extent corresponding to that of the surface folding and thrusting, possibly by downwarping and resorption in the sense of the "Verschlückungstheorie" of Ampferer and Kraus. Similar views have recently also been advanced in respect of the corresponding Swiss features.

(c) The Salt Range has also been interpreted as a *system of fault-blocks* with "boundary faults" at or near the edge of the range. The folding is regarded as a subsidiary feature grossly enhanced by passive gravitational gliding and collapse. From conversations I received the impression that E. S. Pinfold

and H. Crookshank think along similar lines. C. S. Fox (1928, 1945) goes even further and altogether denies the existence of tectonic folding in the beds above the salt marl.

At first sight this conception differs radically from that outlined under (b). Yet, if the fault-blocks could be considered as caused not by tension but by compression, resulting in a shortening of the basement and a crumpling of the superficial strata, then the chief points of disagreement would be eliminated.

ASSUMED EOCENE AGE OF THE SALINE SERIES.

On the premise of an Eocene age of the Saline Series the tectonics of the Salt Range present a problem which seems incapable of satisfactory solution. It is felt that most of the advocates of this view who adopt a 20 mile thrust as a modern and elegant solution of the difficulties have never taken the trouble of considering all the implications of this postulate. Only two comprehensive sections have been published which are based on the Eocene assumption.

G. de P. Cotter (*loc. cit.*) bases his section on the now less favoured idea of correlating the salt marl with the basal Eocene pisolites. It is drawn to an absurdly exaggerated scale of heights but does not involve anything mechanically strictly impossible. It appears highly improbable, however, that the postulated thrust should have developed and stayed in a horizon below the salt, and that the salt should have extruded along this thrust in preference to choosing the easier way along its own place of deposition, which lies higher and is under less pressure. Furthermore it is unlikely that the Soan syncline should, in pre-Ranikot time, have been the place of maximum erosion as well as of maximum deposition. It is interesting to note that, if the salt is considered Cambrian, this section immediately becomes plausible both for the Salt Range and the Kala Chitta Hills, the "décollement" of which would then take place on Cambrian salt instead of on the hard Attock Slates.

The other section has been drawn by D. N. Wadia (1939, Fig. 27). It is mechanically not acceptable, as it shows below the Salt Range scarp an inverted sequence which has no root.

E. R. Gee's clearly described (*loc. cit.*) but unfortunately not illustrated conception of a *pre-Siwalik nappe* is the most attractive of the Eocene hypotheses advanced so far. From the observed fact that in every local fold or thrust the Saline Series—Purple Sandstone or—Talchir contact behaves like a bedding plane it is clear that the postulated major thrust must antedate at least the last phase of folding. By dating the thrust at the Oligocene period of non-deposi-

tion E. R. Gee allows for this and also gives his nappe a free field to advance over an open foreland of plastic salt, without forcing it to overcome the resistance of any overlying Siwalik deposits of which, moreover, no trace has ever been found between the salt and the Palaeozoics.

Unfortunately some of the implications of this clever explanation are not easily understood:

- (a) According to E. R. Gee "an immense overfold passing into an overthrust, was formed along the northern margin of the Salt Range saliferous region and (that) the whole area to the north—including the present Potwar and beyond—slid forward to the south across the lower Eocene salt deposits". Now it is hard to imagine, in fact impossible, that an enormous overfold could consist of the known Cambrian—Eocene sequence alone which we know to be only 4000 feet thick in the west and 2000 feet in the east. The fold must have involved either the pre-Cambrian basement or a pre-Purple Sandstone plastic horizon to stuff its core. Where are these deeper beds?
- (b) Assuming, however, that the thrust developed along a pre-existing fault and involved only a sequence 2000 to 4000 feet thick, the mechanics still remain obscure. It would be easy for such a thin thrust-sheet to glide along comparatively unharmed, once it got on to the plane lubricated by the Eocene salt. But in order to get there it would have to travel an equal distance over a rougher road, and with no weight to keep it together. Surely it would break into dissociated fragments long before it reached the safe ground of the salt.
- (c) The forming of this nappe must have taken a long time: according to E. R. Gee most of the late Eocene and Oligocene. Whether it travelled during a period of emergence or under the sea, it should have left enormous masses of contemporaneous detritus. Yet there is no sign of such deposits.

Though the idea of this nappe has been abandoned by E. R. Gee himself, it was considered advisable to deal with it at some length, because it is sure to be revived in the course of the present controversy.

I have personally made many attempts to find an acceptable structural solution of the Salt Range on the assumption of only one saline horizon of Eocene age but every one of them seems to conflict with one or several of the following observed facts:

The absolute minimum width at which the Saline Series underlies the Cambrian sequence is 10 miles (shortest distance Salt Range front to Vasnal or Kallar Kahar). It is probably greater and possibly even as much as 40 miles (distance Warcha to Kalabagh). If the contact is abnormal, major thrusting is therefore an essential feature of all possible explanations.

As mentioned above the upper boundary of the Saline Series participates in all local folding and thrusting like a normal sedimentary junction. The postulated thrust must therefore be older than the latest folding. There is, moreover, not a single relic of beds higher than the supposed Eocene horizon of the Saline Series to be found between it and the overlying Palaeozoics. The thrusting must therefore be of late Eocene age, or the advancing nappe of Palaeozoic must have brushed the later sediments completely off the salt, or the salt must have left its original position and overflowed the Nimadrics before the thrusting developed.

Where the Saline Series does not come in contact with the transgressive Talchirs, over an area of some 1000 square miles, its roof is always formed by Purple Sandstones, and no vestige of any older Cambrian or pre-Cambrian rocks has ever been seen. The major thrust-plane must therefore practically coincide with a depositional plane at the base of the Purple Sandstone, *i.e.*, be a shear-plane, and the quest for this horizon again arises.*

In spite of many exceptions, the general disposition of the beds within the Saline Series shows a certain regularity and seems capable of subdivision into salt marls and gypsum-dolomite groups. The persistent occurrence of the Upper Gypsum Group just below the Purple Sandstones and Talchirs is particularly suggestive of a fairly orderly arrangement of the Saline Series. If this top gypsum is primary, it seems to preclude any structural explanation based on an intrusion or extrusion of Eocene salt with its concomitant obliteration of depositional sequence.

My endeavours have resulted in only three evolutionary conceptions which might be worthy of some consideration, before they sink into oblivion (Figures : Hypotheses 1, 2, 3).

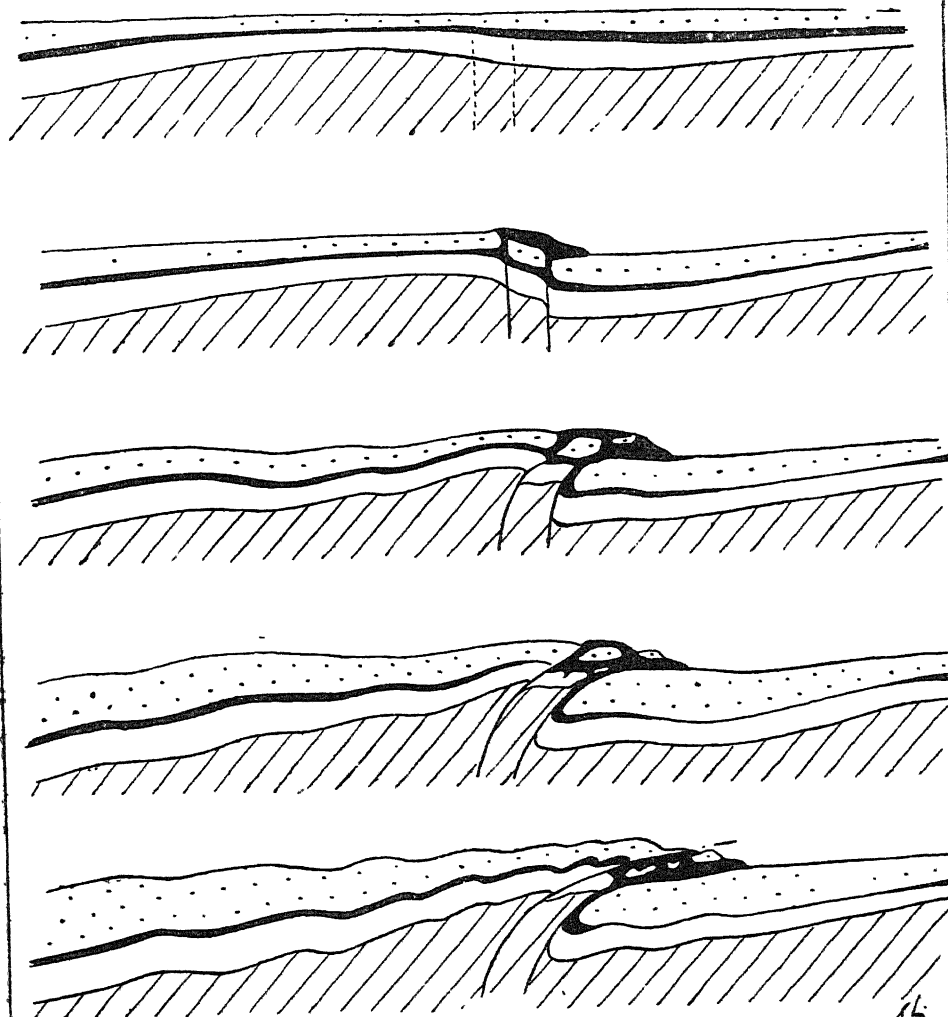
Hypothesis 1 shows early faulting along which salt extruded as soon as the Nimadric deposition in the southern foreland attained a fair thickness. Subsequent pressure from the north converted these faults into thrusts, the extruded salt forming a gliding horizon for the over-thrust units.

*It could, of course, be assumed that the thrust Cambrian sequence was itself an old Palaeozoic nappe which was already detached from the basement and could thus move more freely. This assumption however only shifts the improbable happening into a more distant past.

HYPOTHESIS 1

N.

S.



not to scale


 POST-LAKI
 SEDIMENTS

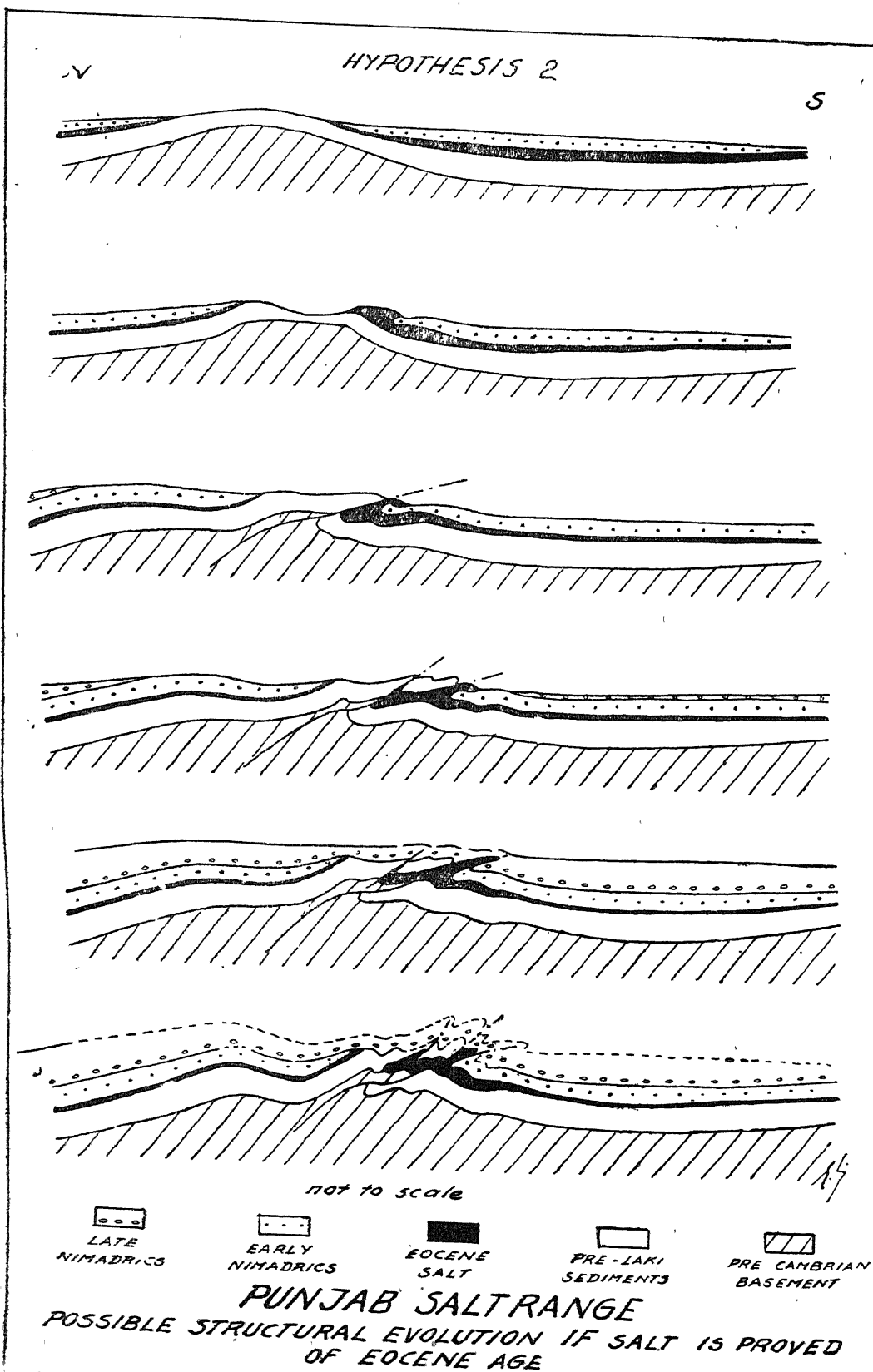

 EOCENE
 SALT


 PRE-LAKI
 SEDIMENTS


 PRE-CAMBRIAN
 BASEMENT

PUNJAB SALT RANGE

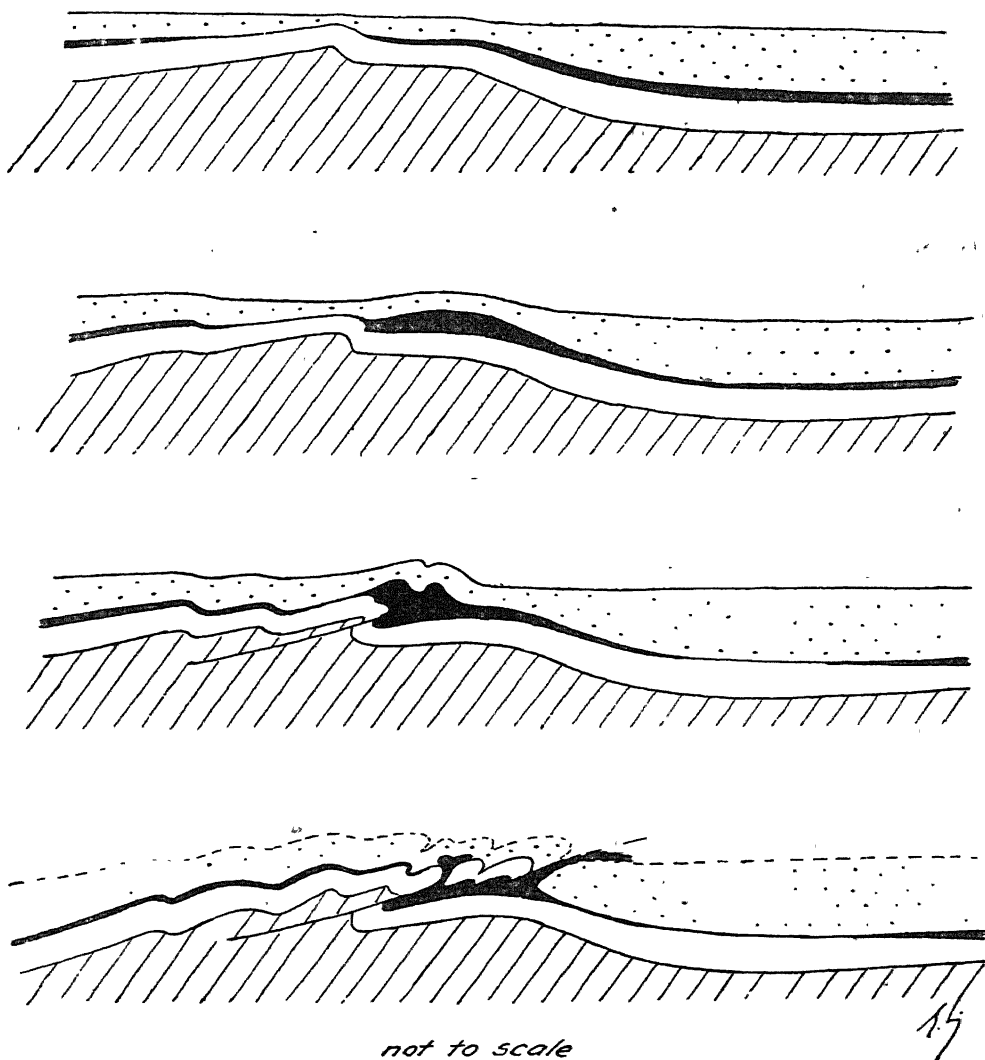
POSSIBLE STRUCTURAL EVOLUTION IF SALT IS PROVED
OF EOCENE AGE



N

HYPOTHESIS 3

S



POST-LAKI
SEDIMENTS

EOCENE
SALT

PRE-LAKI
SEDIMENTS

PRE-CAMBRIAN
BASEMENT

PUNJAB SALT RANGE

POSSIBLE STRUCTURAL EVOLUTION IF SALT IS PROVED
OF EOCENE AGE

Hypothesis 2 also postulates salt flowage to the surface, at a time when the top of the incipient Salt Range was not yet covered by the Nimadrics. Thrusting developed on the steep south-flank of the embryonal range and reached its furthest extent at a comparatively early stage, perhaps after the deposition of the Lower Siwaliks. The whole structure was subsequently covered in by later Siwalik deposits, and the originally fairly flat thrust-plane was finally folded and crumpled during the last main phase of the Himalayan folding. The timing of the movements is later than that postulated by E. R. Gee, since some weight of Nimadrics is needed to make the salt flow.

Hypothesis 3 is similar to the previous but allows for a still later timing of the whole thrusting process, which here originates only after the whole embryonal Salt Range had been covered in by Siwaliks. The upward flowage of the salt was induced solely by the difference in the weight of the overlying beds. This explanation has been attempted, because it is not considered essential that a large time interval must have elapsed between the original forming of the thrust and its subsequent folding and slicing.

Though all of these hypotheses appear to me theoretically acceptable, they are difficult to reconcile with the field evidence, chiefly for the following two reasons.

Firstly, the postulated flowage of the salt seems to be contradicted by the fairly orderly behaviour of the Saline Series and could be accepted only, if the top gypsum, the most regularly placed member, can be proved to be a secondary alteration product formed after the Saline Series had come into contact with Purple Sandstones or Talchirs. In my opinion, the seeming regularity of the remaining saline succession might then become debatable, as I am still a little doubtful about the validity of the Lower Gypsum-Dolomite Group as a well-defined stage.

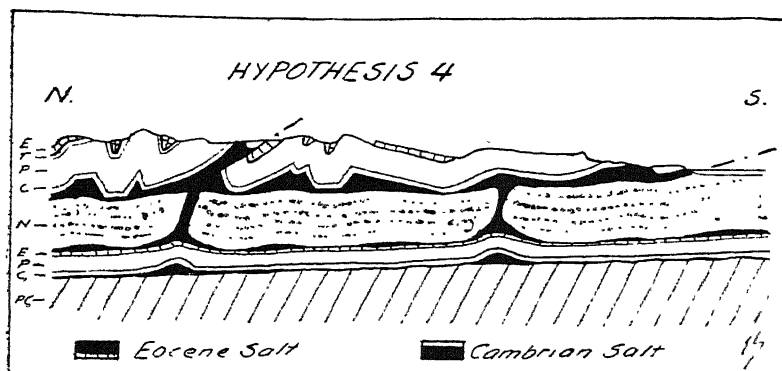
Secondly, the thrust-planes, particularly in hypotheses 2 and 3, had to be given an unmotivated high hade, in order to provide a semblance of probability for the absence of outcrops of any beds lower than the Purple Sandstone. And even so the persistent association Saline Series—Purple Sandstone is not explained.

In spite of my personal belief in the Cambrian age of the Salt, I feel that I have honestly failed in finding an acceptable structural interpretation of the Salt Range on the basis of an Eocene age of the salt. But it is possible and even probable that I have not exhausted the possibilities, and the purpose of this paper will be achieved, if it provokes other attempts at evolving the Salt Range structure from its inception and on a reasonably broad base.

POSSIBLE ADMIXTURE OF EOCENE SALT TO CAMBRIAN SALT.

In concluding I may be permitted to draw attention to another way in which the Cambrian salt beneath the Salt Range may have become contaminated with an Eocene salt. It has occurred to me shortly after my supplementary note to last year's symposium had gone to press (1945).

If the Salt Range is thrust at all, there must be a line along which the Cambrian salt of the overthrust unit comes in contact with the possibly saline Eocene of the northern edge of the southern foreland, and at this contact the two salts might get mixed. In addition it appears possible that the Nimadric cover of an Eocene salt layer in this foreland has been buckled and broken under the weight of the superimposed Salt Range. Through weak spots in this cover Eocene salt may have extruded and spilled into the foreward gliding overthrust Cambrian salt, roughly in the manner indicated.



Punjab Salt Range: Surface geology as along meridian $72^{\circ}10'$ between lat. $32^{\circ}23'$ and $32^{\circ}31'$. Scale: 1 inch = 2 miles. N = Nimadrics, E = Eocene, T = Trias, P = Permian and Upper Carboniferous, C = Cambrian, PC = Pre-Cambrian.

This line of thought is of some interest, as it might provide a clue for the puzzling banding of the salt and the intercalated layers of kallar. Spilling of an Eocene salt into a Cambrian salt at various points of injection presumably resembled the flowing of waters from tributaries into a main stream. Instead of diffusing and mixing, however, the more viscous salt injections were carried forward as distinct, though much attenuated layers. On the other hand, this hypothesis would hardly account for the presence of Eocene oil shales and dolomites.

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A NOTE ON THE SALINE SERIES OF NORTH-WESTERN INDIA*.

By

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GEOLOGICAL SURVEY OF INDIA.

(Received 12th December, 1945)

ABSTRACT.

The Saline Series of the Punjab Salt Range is found under the Cambrian rocks in the eastern area and under the Talchir boulder bed further west. A similar series occurs also in the Trans-Indus region near Kalabagh and in the Kohat district, where it is associated with Eocene rocks. The junction of the Purple sandstone with the Salt Marl almost always shows disturbance marked by brecciation while the similar junction of the Talchir boulder-bed is marked by obliteration of stratification and crushing of the pebbles and boulders. Much has been written on the stratigraphy, structure, origin and age of the Saline Series, the question of age being much debated. The main difficulty is the interpretation of the structures which are complicated by the highly plastic nature of saline deposits which enables them to appear natural even in sections to which they do not belong.

The tectonics of the Salt Range (Cis-Indus) suggest that a satisfactory explanation of the structures and of the high probability of a Tertiary age of the Saline Series can be found in the theory of Continental Drift. The northward drifting of the Indian Peninsula encounters a long stretch of sedimentary strata in its path. If the northern margin of the drifting mass were smooth and even, the strata in front would be merely compressed progressively with the advance of the drifting mass. Complication is introduced by the fact that there are wedges of the Peninsula which now project through (a) Kashmir (Muzaffarabad-Baramula), (b) Mianwali—Kalabagh, (c) Dera Ismail Khan, and (d) Jacobabad—Sibi—Quetta. At the points of these wedges the sediments have been pushed up and gathered together while between the wedges they form arcs or festoons. A relative southerly movement is envisaged in these festoons as the strata forming them must have been to a certain extent free to move while they were subjected to compression by the motion of the Peninsular margin advancing beneath them. The movement of the strata took place along thrust planes parallel to the arcs of the festoons, formed at some distance behind the edge of the sedimentary basin. As the wedges have a general northerly (N.N.W.) direction, the movement is towards the east on their western side, towards west on their eastern side and towards the south in the portions of the festoons away from the immediate vicinity of the wedges.

The Salt Range festoon is affected by the Kashmir and Mianwali wedges, and the Trans-Indus (Chichali-Marwat—Bhattani ridges) by the Mianwali and Dera Ismail Khan wedges. The comparatively large magnitude of the Kashmir wedge is responsible for the greater disturbance suffered by the Punjab Salt Range. The Kohat region is unaffected by the Mianwali wedge which apparently stops at the Chichali Range. Hence there is merely one uninterrupted sweeping curve from the Kashmir syntaxis through the Hazara, Attock and Kohat ranges towards Bannu and beyond. Being some distance to the north from the Salt Range, this arc is comparatively less intensely folded and compressed.

*Communicated with the permission of the Director, Geological Survey of India. The views expressed here are entirely those of the authors. [First received for Poona symposium, 20, Nov. 1944, but permission to print withheld by Dr. Crookshank, Director, G. S. I. B. Sahni].

The full sedimentary succession in the Potwar basin is thrust over the Eocene rocks which were the youngest rocks at the time of the initial movement. The Salt Marl and the associated gypsum formed the horizons along which the thrust acted. The distribution of the Saline Series suggests that it is present in the southern and western parts of the Potwar basin. The later earth movements corresponded to the main upheavals of the Himalayas at the close of the Muree and Siwalik periods respectively. The Potwar basin is covered by thick Siwalik strata which conceal the structures present in the earlier strata under them.

The structures of the basin and the nature of the movements provide good reasons for considering all the Saline Series as of one age. Its age should therefore be that deduced in the less disturbed Kohat region—Tertiary.

INTRODUCTION.

The age of the Saline Series is a major problem of Indian geology which has attracted the attention of several eminent geologists. A. B. Wynne's work (*Wynne*, 1878) some 67 years ago led him to the conclusion that, in the eastern part of the Salt Range, the Saline Series was of Cambrian age. In several sections here the Salt Marl and the associated salt and gypsum underlie the Cambrian succession and occur immediately below the Purple Sandstone. Some 40 years later, Sir E. H. Pascoe (*Pascoe*, 1920, 358 *et seq.*) had occasion to study the Tertiaries of the Salt Range, Potwar and other areas in connection with his investigation of oil occurrences. His observations led him to the conclusion that the Saline Series was of Tertiary age and that its infra-Cambrian position in parts of the Punjab Salt Range was the result of great disturbance and thrust. Amongst other geologists who have made notable contributions bearing on this subject are Mr. C. S. Middlemiss (1891), Dr. Murray Stuart (1919), Dr. W. A. K. Christie (1914), Dr. G. de P. Cotter (1931, 1933), Mr. D. N. Wadia (1929), Mr. E. R. Gee (1934), Mr. E. S. Pinfold (1918); Mr. P. Evans (1935) and Col. L. M. Davies (1929). Mr. Gee has completed a careful and detailed mapping of the area during the last decade and the results of his work have been published recently (*Gee*, 1944) in a rather condensed form. The present position is that there is influential support for both the views.

It is not surprising that such a difference of opinion should exist, for the Salt Range presents a complex series of structures including faults, folds and overthrusts in which both sides should find something to support their arguments.

DISCUSSION.

There is a fairly voluminous literature on the stratigraphy of the Cis-Indus and Trans-Indus regions. In the Cis-Indus region the Saline Series appears at rather different stratigraphical horizons in different sections, but generally at the bottom of the sedimentary column. Near the eastern end

it underlies the Purple Sandstone below the Cambrian *Neobolus* beds, as at Khussak and Khewra. Further west the Saline Series is seen to underlie the Salt Pseudomorph Shales, the Talchir boulder-beds, and the Speckled Sandstones. At the western end of the Salt Range near Daud Khel, gypsum beds are seen over the Nummulitic limestone, and in one place the limestone appears to pass into massive gypsum. On the other side of the Indus river, the Saline Series directly underlies the Middle Siwalik beds. Further north, along the fault zone of the Luni Wahan, it is found below the Lower Siwalik beds. The next series of outcrops is some 16 to 17 miles away to the north in the neighbourhood of Shakardarra (N. W. F. P.), where red or purple clays overlie the Saline Series. These red clays are associated with Nummulitic limestones. One or two small inliers of Salt Marl are also seen about 7 or 8 miles north of Kalabagh. The different stratigraphical positions of the Saline Series in the various sections give room for regarding it as of Cambrian age in the Cis-Indus area and of Tertiary age in the Trans-Indus region.

The sections exposed at Khewra, Warcha, Nilawan ravine, etc. give the appearance of a conformable sequence from the Salt Marl to the Purple Sandstone, *Neobolus* beds and Magnesian Sandstone. Careful observation in some of these sections reveals the fact that the junction of the Saline Series and the Purple Sandstone is disturbed and brecciated, as pointed out by Mr. Middlemiss (1891, *p.* 31) and by Dr. Murray Stuart (1919). Even in the apparently conformable sequence in the Nilawan Ravine there are indications of disturbance. The salt beds often show lenticularity and the included layers of marl give fairly clear indications of schistose structures (*M. Stuart*, 1919, *p.* 60, 82). The marl is apparently structureless and homogeneous. Yet, on close observation, Mr. Middlemiss (1891, *p.* 29) found that the marl showed streakiness and gradual passage into dolomite. The marl layers in the salt lenses have such varying dispositions at the present day that they cannot be attributed to original sedimentation but can be explained satisfactorily as being due to the effect of dynamic stresses (*Stuart*, 1919).

In lithology, the Purple Sandstone resembles some of the Upper Vindhyan Sandstones of Central India and Rajputana which are generally regarded as of Cambrian age; it is also similar to the red shaly formations overlying the marls of the Trans-Indus region and to the red shales of the Chhharat Series in the Fatehjang area. In the absence of fossils (megascopic) in these Salt Range rocks, lithological comparisons leading to widely divergent conclusions regarding their age cannot be considered satisfactory.

The Saline Series (Cis-Indus) has also been compared to a part of the Hormuz Series of Iran in which the salt is regarded as of Cambrian age (Boeckh, Lees and Richardson in "*Structure of Asia*", 1929). But comparisons with Iranian strata are surely far-fetched if we are thereby to ignore the neighbouring Trans-Indus region.

The controversy relates to the age of the Saline Series in the Punjab Salt Range only, for there appears to be general agreement that the Trans-Indus occurrences are of Tertiary age. Though the Kohat region is separated from the northernmost point of the Punjab Salt Range by a stretch of about 17 miles of Siwalik strata, the Saline deposits have similar characters in both the areas such as lenticularity and schistose structure. There is some difference in composition of the salt but this is easily explained. Dr. Murray Stuart has called attention to the fact that the Kohat salt consists mostly of sodium chloride, with some calcium sulphate; the Kalabagh salt begins to show a little magnesium and potassium while containing appreciable calcium sulphate; the Warcha salt contains much magnesium sulphate and some potash salts while the Khewra salt shows the largest amount of potash salts of all. This distribution suggests that the Kohat salt represents the earlier layers of deposition, passing progressively up to the latest stage in the Eastern Salt Range (Khewra). This applies only to the salt beds for, according to Mr. Gee, the full section of the Saline Series is developed in the Eastern Salt Range while only the middle and upper portions of it are seen in the Kohat area. It may be noted that the Salt Range and its Trans-Indus extension (the Chichali—Surghar, Maidan, Khasor—Marwat and Bhattani ranges) form the southern edge of the Potwar basin and its westerly continuation into the Bannu area, while the Kala Chitta and other hills of the Attock district and the hills of the Kohat district further west form the northern margin of the same basin. Both these margins are irregular and highly disturbed, but in different degrees.

Since there is, in our opinion, at least as much evidence in support of a Tertiary age of the Saline Series as in favour of a Cambrian age, we may postulate the existence of a more or less full Tertiary succession in the Potwar basin, including the Saline Series in a part of the Eocene. It is highly probable that a large area in the southern, south-western and western parts of the Potwar basin is underlain by the Saline Series though it may have been sheared off, bodily shifted and over-ridden by earlier strata because of the severe tectonic disturbances suffered by this area.

The present distribution of the Saline Series and the characters of the outcrops are perhaps best explained with the aid of the theory of Continental Drift. The Potwar basin is covered by Siwalik strata but beneath these there is a sequence comprising the Cambrian and extending from the Talchir boulder-bed upward. A gradual regression of sedimentation during the Mesozoic from the east towards the west is noticeable, but the Eocene is again transgressive eastwards and apparently underlies the whole basin as it is seen both on its southern and northern margins. The earliest disturbance of the sedimentary sequence in this basin is to be dated in the Upper Eocene as it is identical with the first Himalayan upheaval connected with the early phase of the northward drift of the Peninsula. This must have corrugated the basin to a large extent, and even produced an overthrust. The second stage of the movement (in the Middle Miocene), if not the first, must certainly have produced the folds, faults and overthrusts along which the strata have moved apparently southwards. This apparent southerly movement in the Punjab Salt Range is due to the compression of the strata finding expression partly in nearly horizontal thrust movement over and against the moving foundation of crystalline rocks. It is reasonable to expect that the sedimentary strata in the basin should shear off and separate themselves from the comparatively more rigid bottom which formed part of the drifting mass.

We should naturally expect the axes of the folds produced by these movements to be roughly parallel to the edge of the Peninsula and perpendicular to the direction of movement. But this is complicated by the fact that there are a few wedges or promontories of the Peninsula in North-western India all jutting out roughly in a N.N.W. direction:—

- (a) The Kashmir wedge into the Muzaffarabad—Baramula area producing the syntaxis described by Mr. Wadia (1932). This has been called the Punjab or Jhelum wedge by some authors.
- (b) The Mianwali wedge through Mianwali reaching up to Kalabagh.
- (c) The Dera Ismail Khan wedge through Dera Ismail Khan to beyond Tank.
- (d) The Jacobabad—Sibi—Quetta wedge.

These wedges of ancient crystalline rocks form part of the foundation on which the sedimentary sequence lies. They have picked up the strata encountered on their path and carried them forward while the intervening portions (between each pair of wedges) form well-marked festoons. The strata

are gathered up tightly at the points of (or just in front of) the wedges while they flow out on either side of each of the wedges in widening folds.

The presence of these wedges explains also how a single movement of the drifting mass can produce movements in different and seemingly contradictory directions all at once in the strata at and near the surface. The strata would naturally tend to eddy round close to the point of the wedges, while moving eastward on the western side and westward on the eastern side. Away from the wedges the strata rapidly swing round to the general trend of the strike as indicated in the middle portions of the festoons.

Another effect of the presence of the wedges should be the development of faults radial to the arcs of the festoons, especially where these show sharp changes of direction, as a result of tension due to the stretching of the strata. Some of the streams cutting across the Salt Range, the Indus at Kalabagh, and the Kurram River south of Isa Khel may be following fault lines. Differential movements of the different segments may occur about these radial faults.

The stratigraphy of the Salt Range suggests that the rocks of the Potwar basin were overthrust to the south along one or more thrust planes until they came to rest in their present position, exposing fine scarps on the convex (south and south-west) side of the Range. Admittedly, the Punjab Salt Range is more intensively disturbed than its Trans-Indus extension (Maidan, Marwat and Bhattani ranges). The reason for this can be understood by a comparison of the forces acting on these two festoons. The Salt Range portion was caught up between the Kashmir wedge on the east and the Mianwali wedge on the west; the former advanced far ahead and must therefore have stretched the eastern end far beyond the limit, thereby breaking it off, and leaving a couple of fragments north of Jalalpur with a trend different from that of the adjoining part of the Eastern Salt Range. This (Punjab Salt Range) festoon has moved further north than the Trans-Indus one because of the great magnitude of the Kashmir wedge affecting it. The Trans-Indus festoon has been produced by smaller wedges and is also far from the range of action of the Kashmir wedge and hence the tectonic disturbance associated with it is decidedly weaker in comparison.

It may be added that the northern border (Attock-Kohat areas) of the basin is not so intensely affected as the southern (Salt Range). The northern border has been caught up by the Kashmir wedge further east, but there is no second wedge to interrupt the even curvature of the festoon so produced.

It is because of this that there is no northward bend in the Kohat region corresponding to the trend of the western (Cis-Indus) Salt Range, for the effect of the Mianwali wedge seems to culminate at the Chichali Range near Kalabagh. The Kashmir wedge has, because of its great magnitude, produced close folding and overthrusting in the arcs accompanying it. The effect of the wedge on the festooned strata on either side will naturally diminish to some extent in proportion to their distance from it.

As already mentioned, the compressive movements in this region must have commenced in the Upper Eocene and been repeated and emphasised in the later movements in the Middle Miocene and late Pliocene, and even in the Pleistocene, as they are the familiar phases of Himalayan upheaval. The rocks involved in the thrust (the thrust-block or nappe) would be the whole sedimentary column overlying the foundations of the Potwar basin. A block, broken off parallel to and at some distance behind the edge of the Salt Range arc, would be thrust over the Eocene rocks which were the youngest rocks at the time of the first stage of movement. The horizon along which the sliding occurred is thought to be a part of the plastic Saline Series, possibly the gypsum formation, as pointed out by Mr. Gee (1934, *p.* 462). During the later movements the Saline Series also may have moved, sometimes together with all the strata and sometimes by itself. The latter would explain the presence of the saliferous rocks in such abnormal positions as have been described by several authors (*e.g.* Pascoe, 1920, *p.* 367).

The Murrees are apparently absent in the southern part of the Potwar basin and the Siwaliks generally lie directly over the Eocene rocks at the top of the scarps and the northern flanks of the Salt Range. The Siwaliks which occupy the present surface of the basin were deposited after the earlier movements and cannot therefore reflect the structures which lie underneath. The movements which affect the Siwaliks are of post-Siwalik age though to a large extent they follow the previous structural lines. Hence a series of more or less parallel pre-Siwalik folds must underlie the Siwaliks. It may also be deduced that the overthrust marking the Salt Range will be succeeded, to the north, by folds gradually diminishing in intensity, but these folds would be only weakly developed in the Siwalik strata at the surface.

CONCLUSION.

The above discussion would show clearly that the Punjab Salt Range, the Trans-Indus Ranges and the Kohat Ranges all belong to one sedimentary basin and not to different units as has generally been implicitly assumed. If

this unity is conceded and grasped, it follows that the Saline Series in the Salt Range is identical and continuous with that in the Kohat region. The less disturbed part of the arc in the Kohat district shows the Saline Series in its natural position, *i.e.* as part of the Eocene succession, while the part forming the Salt Range arc is highly disturbed and the Saline Series overthrust along its southern margin by the whole series of strata in the Potwar basin.

Sir Edwin Pascoe (1920) and Mr. E. R. Gee (1934) have discussed the overthrust origin of the Salt Range and of the structures found therein. Our discussion takes these ideas a step further and gives, it is hoped, an acceptable hypothesis by which the complexities of the geology of this interesting region can be explained.

It is gratifying to know that the problem of the age of the Saline Series is now being attacked from a palaeontological angle by Prof. B. Sahni who has already published some important evidence which upports the Tertiary age. It is hoped that further work on the same lines aided by detailed structural studies will help to solve the problem in a satisfactory manner.

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SEARCH FOR MICROFOSSILS IN THE PURPLE SANDSTONE, KHEWRA GORGE.

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The recent discovery by Professor B. Sahni of numerous microfossils of post-Cambrian age in the Saline Series of the Punjab Salt Range, has reopened the old controversy over the age of these strata. As a result, a series of papers has been published (*Proc. National Acad. Sci. India* 1944, **14**, 6) in which, among other questions, the age of the Purple Sandstone has also come under some discussion.

The Purple Sandstone is a series of strata attaining a thickness of several hundred feet which have hitherto yielded no organic remains whatever, but most geologists regard it as a part of the Cambrian series. This opinion is based partly upon the general lithological resemblance with the Vindhyan Sandstone of Peninsular India; partly also upon the fact that the Purple Sandstone directly underlies the Neobolus Beds, of which the Lower Cambrian age is indicated by fossil evidence. On the other hand, it has been suggested by more than one geologist that the Purple Sandstone may be of Tertiary age. This view was first tentatively suggested by Sir Edwin Pascoe in 1920 (*p.* 363) but he has since withdrawn it (1945 *pp.* 206-207). Recently, however, N. L. Sharma (1945 *p.* 260) has revived the idea, while Lamba (1945 *p.* 223) definitely assigns the Purple Sandstone to the Tertiary.

In the hope that a micro-analysis of the rock might throw some light on the question, one way or the other, I undertook a search for possible evidence of microfossils in some samples collected by Professor Sahni in the Khewra gorge. Although only a small amount of the rock has yet been examined it may be of some little use (pending a fuller investigation) to present the results here, for what they may be worth.

The few specimens examined (registered as Nos. S35 and S36) come from the massive upper part of the Purple Sandstone proper (that is, not from the lower, flaggy, Maroon Shales stage) as exposed about a mile north of Khewra where the gorge suddenly narrows and the massive Sandstone, here striking

across the ascending road, is now being cut by the stream. The work here presented was done during two distinct periods: in 1944 when Schulze's macerating mixture ($\text{HNO}_3 + \text{KClO}_3$) was used and in 1945 when HF was employed for breaking down the rocks. In each case the fullest precautions were taken to avoid contaminations. The rock sample was first ground on all sides, then washed with distilled water and finally passed through a gas flame before it was put into the dissolving jar. It will be convenient to deal with the work separately under 1944 and 1945.

1944.—Specimen S35 is a large slab showing wide suncracks which have been subsequently filled with detrital material. A fragment about 10 gms in weight was taken from the solid homogeneous part of the slab, carefully avoiding all cracks* and 30 preparations were made.

Specimen S 36 is a smaller, ripple-marked slab, with no evidence of suncracks. About 5 grams of this rock was examined, in 32 micro-preparations.

Neither of the fragments examined yielded any trace of organic remains.

1945.—This year I examined some further samples, using dilute hydrofluoric acid, which, while dissolving the sand particles, would leave intact any organic remains in the matrix. Care was taken to select samples from the solid sandstone, avoiding all cracks. From each of the slabs S35 and S36 about 30 to 40 grams were dissolved and in each case 10 slides were prepared. The result as regards microfossils was again completely negative.

DISCUSSION.

We have seen that an examination of 82 slides prepared from two specimens has failed to show any remains which can be regarded as being of organic nature.

The Tertiary rocks in this area (belonging to the Saline Series) have been studied by several workers in this laboratory and they have always readily yielded plant fragments. If the Purple Sandstone were a Tertiary deposit, any fossil fragments in it would hardly have escaped observation in the numerous slides that were prepared. The absence of all trace of plant microfossils thus supports the view that the Sandstone is of very ancient date.

*This detrital material was also subjected to a search for microfossils and from about 19 gms. of this material, 30 preparations were made. In these preparations three small brown roughly spherical bodies were observed, which appear to be of organic origin, though their exact nature is unknown. It would, however, be risky to make any use of these presumably fossil bodies in deciding the question at issue, even if we knew their affinities, because the detrital matter may be of mixed origin.

It must be admitted that such negative evidence, to be of any substantial value, should be more broad-based. Further specimens, from different localities, should be examined. But so far as these meagre data go, they afford no support to a Tertiary age for the Purple Sandstone.

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FURTHER NOTE ON THE AGE OF THE SALINE SERIES OF THE PUNJAB AND OF KOHAT.

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(With plates 1-19)

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I. INTRODUCTORY REMARKS

In my contribution to the first Symposium held at Poona last year (Gee, 1944, *Proc. Nat. Acad. Sci. Ind.* **14**: 269-312) a summarised account of the stratigraphy and geological history of the Salt Range area was included. That summary was based on the fairly detailed geological mapping of the whole area, and of adjoining areas to the west of the Indus river.

Although I was unable to attend that Symposium, I have read the contributions of others with great interest, and I now propose to comment on certain of the points raised.

Since that Symposium was held, I have had the pleasure of visiting what I regard as the critical sections of Salt Range geology in the company of Professor Sahni and of Mr. Coates. During the latter part of this second excursion, we were joined by Mr. Pinfold. It was very unfortunate that Mr. Wadia and Dr. Mahadevan, who we had hoped would attend, were unable to do so on account of other engagements. I propose, in this second contribution, to describe briefly the results of the 1945 excursion.

II. COMMENTS ON PAPERS SUBMITTED TO THE SYMPOSIUM HELD AT POONA ON THE 29th AND 30th DECEMBER, 1944.

The opening paper by the President of the Academy, Professor Sahni, embodies the results of much careful laboratory work, combined with field-studies, carried out by him and his research assistants, especially Mr. Trivedi.

They have shown that vegetable remains, apparently of gymnospermous and angiospermous type, occur at the present day in the rocksalt, marl and dolomite of the Punjab Saline series. In addition, they have shown that vegetable remains occur also in the shales (including kerogen shales) which are undoubtedly a part of that series. I realise that these minute plant fragments have not introduced themselves into the argument in the laboratory but are derived from the specimens examined. The possibility of microscopic plant-fragments having found their way into rocksalt, associated saline marl (*Kallar*), gypsum and dolomite at a time subsequent to the deposition of these saliferous deposits has, however, to be reckoned with. The case of the oil-shales is, I consider, rather different. It is agreed that the kerogen and free oil is indigenous in the shales, and that it has been derived from either vegetable or animal remains. No evidence of animal remains within the oil-shales has been met with, though many geologists have made an intensive research. What is the evidence of the plant remains that have so far been recognised in these oil shale strata; can they not possibly represent a Cambrian flora? That is one of the most important questions to decide.

Professor Sahni has then dealt with the possibility of attacking the problem from the point of view of the magnetic orientation of the rocks near the junction of the Saline series and the overlying strata. This method was considered during the recent excursion and, although one could obtain samples of the Purple Sandstones for examination in this way, the difficulty is of collecting suitable rocks from the Saline series beneath the junction. The only rock-types likely to prove at all suitable appear to be the Khewra trap, but this is usually much weathered and jointed. Apart from this, differential movement may in a number of instances have occurred during the late Tertiary to sub-Recent folding and shearing. The determination of the age of the Khewra trap on the basis of its radio-active elements would, however, be of much interest, as the evidence is strongly in favour of it being a contemporaneous lava-flow as opposed to an intrusive sill. To suggest a correlation of this phase of vulcanicity with the latest phase of Deccan trap activity is, of course, attractive from the Eocene standpoint. Were it Eocene in age, it is surprising that similar flows are not found within the Laki-Khirthar sequence of the Salt Range plateau or at least in the area between the Salt Range and lower Sind.

Coming now to the question of a post-Nummulitic overthrust in relation to the Tertiary orogeny of North-West India; supporters of the Cambrian view admit freely the evidence of fold-faulting and thrusting in the Salt Range

region. These late Tertiary structures adequately explain the physiography of the region, without necessarily invoking the assistance of a regional thrust.

As regards the occurrence of oil at such an early geological age, one might draw attention to the foetid dolomites of definite Cambrian age at Saiduwali in the Khasor Range (Trans-Indus), to indications of oil in the Vindhyan limestones of the Katni area and to the occurrence of bituminous anhydrite and dolomite in a bore-hole in the Vindhyan at Nagour, Jodhpur State. As evidence of plant life in early Palaeozoic times, one might also refer to the oil shale deposits of Ordovician age in Esthonia.

Passing on to Mr. Wadia's contribution, one admits the evidence of late Tertiary to sub-Recent fold-faulting and thrusting in the Jogi Tilla area, sections which I have also examined. But, as Dr. Lehner pointed out in the discussion, such evidence in no way favours an Eocene age for the Saline series; in fact, it favours the Cambrian view for, were the upper surface of the Punjab Saline series a plane of earlier low angle thrusting, one might have expected the later shear-planes to have followed the same horizon. The thrust-structures, there displayed, do not follow one horizon but exhibit very apparent discordances along the planes of thrusting.

Referring briefly to the paper by Mr. B. S. Lamba, I would draw attention to the following statement—'If the analogy with the strata met with in the oil-fields of the Punjab is accepted (as it cannot be denied from the sequence met with in Kohat) then the Purple Sandstone immediately above the Saline series has also to be included in that series.' The evidence of the junction between the topmost Purple Sandstone beds and the fossiliferous Neobolus Shales (of undoubted Cambrian age) is sufficient to prove that at least the upper, arenaceous portion of the Purple Sandstone series is of pre-Neobolus Shale age. The basal bed of the Neobolus Shales is a characteristic conglomerate, recognisable over very wide areas and resting with a normal sedimentary contact on the maroon and buff-coloured sandstones of the Purple Sandstone series. As regards the maroon flaggy sandstones and shales of the lower part of that series, the evidence is all in favour of their being a part of the Purple Sandstone series, laid down under similar, shallow water, arid conditions. If, therefore, it is necessary to introduce the assistance of a low angle thrust-plane in order to explain the stratigraphical sequence now displayed in the eastern and middle parts of the Salt Range, the thrust in question must come *below* the maroon shales, that is between the Purple Sandstone series and the Punjab Saline series.

Dr. L. M. Davies' contribution includes very interesting observations on palaeogeography during the Eocene. In Sir Cyril Fox's paper, we have suggestions regarding the mode of introduction of the plant-fragments into the soluble rocksalt and associated deposits. I cannot, however, agree with his conclusions regarding the age of Kohat salt, which he regards as Cambrian also. Equally, do I disagree with the statement that there is little palaeogeographical evidence in support of an Eocene age for those deposits. Apart from the fossils found within the gypsum overlying the rocksalt, the evidence of Eocene palaeogeography in the northern Punjab and in the Kohat district (N.W.F.P.) indicates that earth-movements resulting in the formation of shallow inland seas, favouring salt deposition, might well have occurred during Laki-Khirthar times. Mr. Pinfold's valuable contribution demonstrates this feature very clearly.

Dr. Chhibber's suggestions regarding silicification as a result of super-heated waters derived, apparently, from the same source as the Khewra trap, are very interesting, but I do not think the same phenomenon can be made use of to explain the cherts in the Eocene limestones. Such cherts are not confined to the Eocene beds in the Salt Range; cherty horizons are also occasionally met with in the Productus Limestones. When Dr. Chhibber remarks on the brecciated nature of the junction with the Purple Sandstones, it is apparent that he has examined only a very limited number of sections. Admittedly, the junction is brecciated or disturbed in many places, but it is undisturbed by tectonic movement in many others.

Regarding Mr. Sharma's contribution, I pointed out in my written comments last year that the junction between the Purple Sandstones and the Eocene in the Dandot gorge section is undoubtedly a faulted one, as will be observed by mapping the strata on either side of the gorge.

Dr. Lehner's dissertation on the Persian salt formations is most valuable. His second paper, written with the object of bridging the gulf between the Cambrian and Eocene views, is ingenious and might explain the occurrence of the plant-fragments in the salt, kallar, etc., but we are still left with those in the oil-shales of the Upper Gypsum-Dolomite stage at the top of the Saline series.

We were all glad to see the brief contribution by Mr. Middlemiss—one of the pioneers of Salt Range and Himalayan geology. His death during the past year is greatly regretted. Middlemiss' reference to the 'very rarely exposed brecciated border' of the Salt Marl against neighbouring formations

is somewhat difficult to understand, for the junction beds are often well exposed. His statement probably arises from the fact that he examined only separate, widely-spaced sections, though admittedly in detail, and did not carry out continuous mapping. Also, his reference to 'the almost universal absence in it (the Saline series) of any sedimentary detrital material, or of stratified divisional planes' is scarcely correct. Probably, he was thinking only of the salt-bearing marl, for the associated shales and sandy dolomites of the upper and lower stages of the series are well-stratified.

Finally, the contribution by Dr. A. Lahiri on the bituminous shales from both the Punjab and the Kohat Saline series is of much interest and clearly shows the presence of vegetable remains. But, so far as can be judged from the photographs, none of these plant-fossils in the sections of Salt Range oil-shale (from Warcha, Makrach and Kalabagh) show definite post-palaeozoic plant-structures. Also, referring to his comments on the Kalabagh occurrence, I would point out that the oil-shales of Kalabagh occur below the salt-bearing stage whilst those of Kohat occur above it.

And so, at the end of the 1944 symposium, we were left with the problem apparently unsolved—though I would mention that those geologists who had examined the critical sections around Warcha and below Sakesar all agreed that the Saline series had been initially deposited in early Cambrian or pre-Cambrian times.

I will now pass on to the second excursion held in October last.

III. RESULTS OF THE EXCURSION HELD IN OCTOBER, 1945.

The excursion commenced at the western end of the Salt Range with visits to the Kalabagh and Mari Indus salt-hills. From Mari Indus, we also visited the interesting sections north-east of Daud Khel where massive Eocene gypsum is met with and the most westerly outcrop of the Talchir boulder-bed of the Salt Range occurs.* (See Plates 2 and 3.)

From Mari Indus, we moved to Warcha Mandi, Chittidil and Sarai (below Sakesar mountain) where we again examined the sections visited by the excursion of 1944 and also additional sections near Ratta and Amb.

We then visited Khewra and Kallar Kahar and from there proceeded to Jalalpur at the eastern end of the Salt Range, south of the Jogi Tilla area. (See Plate 1.)

*The Talchirs with Speckled Sandstones and Lavender Clays are also well represented in the southern part of the Khasor Range to the west of the Indus river.

Brief notes on the results of this excursion are given below.

(1) *The Kalabagh-Mari Indus area* (Sheet No. 38 $\frac{P}{9}$ -)

(See Plates 3, 9, 11, 12 and 13).

The complicated tectonics of this area were noted, in which the rocksalt and marl have played an important part. Although at first sight it appears that Siwalik beds have been deposited directly on the folded Saline series over most of the area, on closer examination we find irregular intercalations of pre-Tertiary rocks occurring between the Salt Marl and the Siwaliks along the eastern slopes of the hill above the salt-mine, while in the western slopes a huge wedge of sharply folded Mesozoic and Permian rocks rests directly on and against the disturbed Saline series. To explain these tectonics it appears necessary to invoke the upward "intrusion" of the Saline series at the apex of this Mianwali re-entrant.

It was noted that the gypsum-dolomite-blue green clay beds that crop out along the right bank of the Indus river at the southern foot of Kalabagh hill closely resemble the sequence met with below the Salt Marl stage around Warcha. These beds again occur along the western side of the hill where they include intercalations of oil-shale, described in the paper by Dr. A. Lahiri at the end of the first Symposium.

(2) *The Daud Khel area.* (Sheet No. 38 $\frac{P}{9}$)

(See Plates 2, 9 and 13).

As previously described, the sections here include —

- (a) Definite evidence of massive Eocene gypsum, capping fossiliferous, Laki shales with limestones and overlain by a thin zone of dark red clay-shales (probably Lower Chharats), the latter being succeeded by the Nimadric sequence. These beds are regularly disposed, though often dipping at steep angles. They are best observed in the hill-section north of the Jaba nala.
- (b) Massive gypsum with dark red and green marl, undoubtedly belonging to the Punjab Saline series, in contact with and overlain by thick, dark-coloured Talchir conglomerates, typical of the sequence of the western part of the Salt Range (*e.g.* between Buri Khel and Pai Khel). These beds occur in the foothills around pt. 1127.

The above-mentioned outcrops of Eocene gypsum (to the east) and of the Punjab Saline series—Talchir rocks (to the west) are separated from one another by a faulted rift of Siwalik strata that decreases southwards to less than $\frac{1}{4}$ -mile in width.

That two gypsum deposits of such varying ages should occur so near one another is, admittedly, a coincidence—this fact has been observed previously. At the same time it is necessary to point out that the two gypsum sequences exposed are of very different type. In the Eocene series, the gypsum is of very pure quality, massive and white to light yellowish-grey in colour. Intercalations of yellow-green clay-shale, similar to the underlying Laki shales, occur in the lower part of the stage. There is also an absence of bi-pyramidal quartz crystals. On the other hand, the gypsum of the Punjab Saline series, associated with the Talchirs of hill 1127, is mainly pink to light red in colour. It includes quartz crystals together with intercalations of dark red and blue-green marl. On lithology, therefore, the two occurrences are very distinct.

Still more important is the evidence, at this locality, of a pre-Talchir age for the pink (Punjab Saline series) gypsum sequence of hill 1127. This is observed in tributary *nalas* which traverse the lower Talchirs and the Talchir/Saline series junction of the southern part of ridge 1127. Here, the beds are vertical or steeply-dipping towards the southwest. As in many other areas where the Talchirs rest directly on the marl and gypseous marl of the Punjab Saline series, the basal few feet of conglomerates are of a reddish, chocolate tinge as opposed to the dark grey, greenish-grey and black matrix of the higher Talchirs. This feature, as previously observed, suggests that a portion of the sediment that forms the basal Talchirs was derived from the adjacent (underlying) Saline series formation. In addition, however, more convincing evidence is observed. Within the basal 10 feet of the Talchirs, several fragments of pink gypsum occur as pebbles in the gritty, clay-shale matrix of the conglomerates. The pebbles observed varied up to about $1\frac{1}{2}$ inches in size. They are not numerous in occurrence, but those observed were carefully scrutinised and there appeared to be no doubt that they are *in situ* in the basal Talchir conglomerates and had not been introduced during the Recent denudation of the *nalas*. The gypsum fragments were of the same pink colour as that of the Punjab Saline series a few feet below, and it is difficult to imagine that they were not derived from the similar beds of that series at the time of deposition of the basal Talchir sediments. Assuming local undulations in the pre-Talchir land-surface, for which there is good evidence in other areas, the sea-currents

of early Talchir times could be expected to erode the higher undulations of the sea-floor and so result in an admixture of red marl and of gypsum fragments within the basal Talchir sediments.

In addition to these smaller pebbles, one large 'boulder' of pink gypsum, with irregular minor intercalations of dark red and blue-green marl, was observed within the lower Talchir conglomerates about 30 yards south of the point where the main tributary cuts across the Talchir-Punjab Saline series junction (about 300 yards southeast of pt. 1127). This boulder measures about 12 feet by 8 feet. Its contact with the gritty shales of the Talchirs which enclose it was carefully examined. The boulder occurs about 15 feet above the base of the Talchir series, that is within the lower part of the dark grey, gritty conglomerates. On the *upper* side of the boulder, the adjoining one to two feet of Talchir shales are of a reddish tinge, which might well be due to the admixture of red marl, originally associated with the gypsum-marl boulder. The surrounding Talchir shales are jointed, as is usual with these sediments, but there was no evidence of shearing. The conclusion arrived at was that the boulder is *in situ* in the lower Talchirs, and had in all probability been derived by the erosion of the near-by Punjab Saline series which formed the pre-Talchir sea-floor in that area. The similarity of the pink gypsum (with red and blue-green marl intercalations) of which the boulder is composed and the gypseous beds of the Punjab Saline series that form ridge 1127 is very striking.

The above-described evidence is, I consider, critical in determining the age of the Punjab Saline series and corroborates that observed at the junction between that series and the Talchir beds in the Chittidil-Sakesar area to the southeast.

(3) *The Chittidil-Sakesar-Amb area* (Sheet Nos. 38 $\frac{P}{14} + \frac{P}{15}$)

(See Plates 8, 9, 12 and 14).

A geological map of the Chittidil-Sakesar-Amb area, around the Dhodha Wahan is included as Plate 3 of my contribution to the first Symposium and the geology, with particular reference to the age of the Punjab Saline series has there been described in detail. As will be gathered from that description, the evidence indicative of a Cambrian or pre-Cambrian age for the series is based on a study of the junction between the series and the overlying Talchir (Upper Carboniferous) and Purple Sandstone (Cambrian or pre-Cambrian) sediments. During the present excursion, by halting one night at the hamlet of Sarai half-

way up the slopes between Chittidil and Sakesar mountain, we were able to study these sections further afield than was the case in November, 1944.

Briefly, the geology critical from the point of view of the age of the Punjab Saline series includes the three stratigraphical repetitions of—

- (a) The Chittidil—hill 2055 area, near the exit of the Dhodha Wahan (this is the lowest repetition).
- (b) The Amb repetition, including the Punjab Saline series outcrop at Amb village to the southeast of the Dhodha Wahan and its continuation westwards and W. S. W. across that gorge to the Sakesar pony-track about one mile north of Chittidil Rest House, where it links up with the third (uppermost) repetition.
- (c) The higher northwestern slopes of the Dhodha Wahan, west and southwest of the small habitation named Ratta, and crossing the Sakesar pony-track about a point one mile north of Chittidil Rest House.

These three sequences might be designated—the Chittidil repetition (lowest), the Amb repetition (intermediate) and the Ratta repetition (upper most). They are shown graphically in Text Fig. 4 of my contribution to the first Symposium.

In the Chittidil (lowest) repetition, the Cambrian (and possibly pre-Cambrian) is represented by the Punjab Saline series with rocksalt, followed above by the Purple Sandstones, fossiliferous *Neobolus* Shale—Magnesian Sandstone sequence, and the Salt Pseudomorph beds with thin pink gypsum in the basal horizons. This sequence is overlain by the Talchir Boulder-bed, the junction being markedly unconformable.

A thrust, cutting sharply across the sequence of the Chittidil repetition, brings in the Amb repetition where, as a result of the Talchir unconformity, the sequence includes the Punjab Saline series (with some rocksalt, and capped in places by massive jointed dolomite) and typical Purple Sandstone beds. The latter are, however, directly overlain by the Talchir Boulder-bed, as also in the Dhodha Wahan, but further west up the slopes towards the Chittidil-Sakesar pony-track, the Talchirs rest directly on the Punjab Saline series.

A second thrust, again markedly discordant with the sequence of the Amb repetition, brings in the Ratta repetition in the higher, right-hand

slopes of the Dhodha Wahan. In this upper, Ratta sequence, as a result of the Talchir overlap, the Purple Sandstone series is entirely absent and the Talchir Boulder-bed rests directly on various horizons of the Punjab Saline series.

During our excursion in November, 1944, we had examined these three repetitions on the Chittidil side of the Dhodha Wahan. In the case of the upper (Ratta) repetition, we had examined this closely for a distance of about $\frac{3}{4}$ mile N.N.E. of the Chittidil-Sakesar pony-track and also westwards to the Golewali gorge, in which area the Talchir conglomeratic shales rest with a sedimentary junction usually directly on the red Salt Marl stage, the middle stage of the Punjab Saline series. During the second excursion in October last, we again examined the sequence in the lower (Chittidil) repetition around hill 2055; in addition we visited the middle (Amb) repetition near Amb village, whilst in the case of the upper (Ratta) sequence we followed the Talchir/Punjab Saline series junction further north-east and E.N.E. to within half-a-mile of Ratta, examining various sections in detail. The evidence of these additional sections add, in my opinion, further convincing evidence in support of the Cambrian (or pre-Cambrian) age of the Saline series. Also, they again demonstrate the occurrence of kerogen shales (with a small proportion of free oil) in the topmost stage (Upper Gypsum-Dolomite stage) of that series. (See Pl. 14).

As briefly mentioned in my contribution to the first Symposium, the stratigraphical sequence of the upper (Ratta) repetition for some distance N.N.E. of where it crosses the Chittidil-Sakesar pony-track about one mile north of Chittidil Rest House (*see* Plate 3 of my published contribution to the 1944 Symposium), includes typical Talchir conglomeratic shales, mainly dark grey to almost black in colour, resting directly on the red Salt Marl beds of the middle stage of the Punjab Saline series, the junction being an undisturbed, sedimentary contact. Traced northeastwards and E.N.E. towards Ratta, the same Talchir sequence and younger sedimentaries continue with remarkable regularity, forming clearly exposed outcrops (*see* Plate 5, Fig. 2 of my published contribution). Followed in the direction of Ratta, the Talchir/Punjab Saline series unconformity decreases progressively in intensity and higher horizons of the Saline series, represented by massive dolomite with cherty dolomite and kerogen shale—the Upper Gypsum-Dolomite stage of the series—come in below the unconformity.

The sequence included in this topmost stage of the Punjab Saline series is very clearly exposed in the scarp slopes at the tributary gorge about 5 furlongs west of Ratta where, along with the overlying basal Talchirs, it consists of:—

- | | | |
|--|---|---|
| <i>Talchir Boulder-bed</i> | { | <p>(f) Thick, greenish-grey, and dark-grey, jointed, gritty shales with rounded and facettled boulders of granite, quartzite, etc.</p> <p>(e) Light grey, gritty dolomite with similar Talchir pebbles and boulders embedded or partially embedded; thickness 6 inches to one foot.</p> |
| <p>..... [An undisturbed, sedimentary contact. The basal bed (e) consists mainly of dolomite and passes down into the purer dolomite (d) of the underlying Saline series. The Talchir boulders embedded in it are not sheared.].....</p> | | |
| <i>Punjab Saline series</i> | { | <p>(d) Massive and bedded, jointed, white and pink dolomite, in part pitted—30 feet.</p> <p>(c) Banded, dark coloured chert and cherty dolomite alternating with thin bands of dark grey and black shales including kerogen shale, the latter up to a few inches thick;—10 feet.</p> <p>(b) Green-grey clay-shales with a 2-inch band of dolomite near the top—5 feet.</p> <p>(a) Thick maroon, streaked green-grey, shaly marl, which passes below into bright-red, gypseous marl with massive white and pink gypsum and dolomite in the lower part.</p> |
- (total thickness exposed is about 200 feet).

To my mind, there is no doubt that the junction of the Talchirs and the underlying dolomite (Punjab Saline series) is an undisturbed sedimentary one; that is to say, the Saline series is here pre-Talchir in age.

The top surface of the dolomite is characteristic of an eroded sea-floor, the top six inches or so having softened and become intermixed with the incoming Talchir sediment including typical Talchir boulders. It is, I think, quite impossible to regard the junction as a line of thrusting along which brecciation has now been obscured by subsequent reconsolidation.

It is also important to note that, where the Talchirs rest on the dolomites, as opposed to the red Salt Marl, the basal conglomeratic shales do not exhibit a reddish tinge.

The above sequence continues eastwards along the slopes towards Ratta. In the opposite direction, towards the Chittidil-Sakesar pony-track, the overlap of the basal Talchirs brings the conglomerates on to lower horizons of the Upper Gypsum-Dolomite stage, so that the Talchirs rest on the cherty dolomite horizon (c)*, and a short distance further W.S.W. they lie directly on the red marl zone (a)*. As mentioned in the joint note published in *Nature* after last year's excursion, it is a question of ordinary sedimentary overlap, and at the locality where, on regional grounds, one would expect such, of overlap the Talchirs. Equally, the kerogen shales at the base of the dolomite must be of the same pre-Talchir age as the remainder of the Punjab Saline series.

That the Punjab Saline series above-described is undoubtedly the same as that which underlies the Purple Sandstone series of the middle and lower repetitions of this area is apparent from a comparison of the above-described section 5 furlongs west of Ratta and the sequence seen at Amb village. There, the middle (Amb) repetition is thrust over Speckled Sandstones of the lower (Chittidil) repetition and includes:—

Talchir Boulder-bed.

.....(unconformable sedimentary junction).....

<i>Purple Sandstone series.</i>	{	Maroon sandstone stage.
	{	Maroon shales and flags.

.....(junction undisturbed and apparently conformable

<i>Punjab Saline series</i>	{	White and pinkish, pitted, jointed dolomite; 25 to 30 feet.
		Maroon, streaked with grey and grey-green shaly marl passing down into bright red gypseous marl and more massive, white and pink gypsum below; about 150 feet.

From Amb, this sequence of the Punjab Saline series continues westwards across the Dhodha Wahan and up the slopes towards the Sakesar pony-track where it locally includes some rock-salt. It is undoubtedly the same series as underlies the Purple Sandstones of the lowest (Chittidil) repetition of hill 2055 and occurs elsewhere in the Salt Range either directly beneath the maroon shales

*Of the section quoted on the preceding page.

and flags of the basal part of the Purple Sandstone series or beneath the basal Talchir conglomerates. As previously concluded, the Punjab Saline Series (including the kerogen shale of the Ratta area) is, therefore, not only pre-Talchir in age but also pre-Purple Sandstone, that is to say, it is either Cambrian or pre-Cambrian.

During the excursion, we also observed the close lithological similarity between the dark red flags and shales of the Salt Pseudomorph series (around hills 2055), the maroon flags with shales of the lower part of the Purple Sandstone series and the shaly red marls of the Salt Marl stage of the Punjab Saline series, suggesting very similar conditions of deposition. The basal beds of the maroon shale stage of the Purple Sandstone series are in places traversed, along the joint-planes, by fibrous gypsum; also thin bands of gypsum $1/8$ to $1/4$ inch thick occur along a number of the bedding planes of the lower maroon shales and flags. Although this latter gypsum may be *in situ* in the Purple Sandstone series as it appeared to be at Warcha, it might also have been brought up in solution from the top gypsum beds of the underlying Saline series.

(4) *The Warcha-Fatehpur Maira area.* (Sheet No. 38 $\frac{P}{15}$).

The Warcha-Fatehpur Maira area is also included in the geological map forming Plate 3 of my contribution to the 1944 Symposium. (See also Pls. 8, 15 and 16 below). Particular attention was given to the following points:—

- (a) The intimate association of the banded rocksalt, with kallar, gypsum and dolomite and the Recent to sub-Recent gravels and boulder-beds as exposed in the New Low Level Tunnel at the southern end of the Warcha Salt mine.
- (b) The undisturbed nature of the maroon shales and flags of the basal part of the Purple Sandstone series in certain sections just east of Warcha Circuit House and in the lower part of the Fatehpur Maira gorge, where these beds overlie the Upper Gypsum-Dolomite stage of the Punjab Saline series.
- (c) The relation between the 'oil-shale' stage of the Warcha and Fatehpur Maira gorges and the overlying Salt Marl stage.

Regarding (a), it was apparent that the rocksalt and kallar, with associated gypsum and brecciated dolomite bands had in very Recent times flowed forward towards the Warcha gorge for a distance of at least several hundred feet, over-riding unconsolidated, or partially consolidated (by brine solution), sub-

Recent boulder-beds, and scree material including pebbles of *Productus* Limestone (Permian). In spite of this, the salt and kallar had by now acquired a definite banding, exhibiting overfolding and contortion. Further within the hillside, this banded rocksalt, etc. continued as the 'normal' banded salt of the Warcha Mine-chambers. It was apparent that contamination of the rocksalt, etc. by sub-Recent extraneous material (including plant-fragments) could easily have taken place up to the vicinity of the mine chambers, and possibly within the chambers also, during Recent times.

Regarding (b) the conformable junction of the maroon shales and flags (with some interbedded gypsum) of the lower part of the Purple Sandstone series and the top gypsum of the Punjab Saline series was again observed. It was also noticed that, as a result of the weathering of the gypsum outcrops, the bedded dolomite and cherty dolomite that occurs within this upper stage is often obscured and is only visible in the recently eroded nala-sections.

Also, it was observed that, where the two series are obviously repeated by a reversed fault—as in the eastern slopes and in the left side of the main Warcha gorge about 400 yards upstream from the Salt Mine—the shear-plane cut obliquely across the bedding of the maroon shales and flags and has caused the brecciation and contortion of the beds above and below the fault.

Regarding (c), we noted the close similarity in the sequence of the gypsum-dolomite-oil shale stage, which crops out beneath the salt-bearing marl in the Warcha and the Fatehpur Maira gorges. This sequence, as exposed, is about 100 to 140 feet thick, but crops out extensively in both gorges as a result of repetitions due to faulting and fold-faulting. In all the exposures, dark red salt marl, of the Salt Marl stage of the Punjab Saline series appears to overlie the gypsum-dolomite-oil shale stage, though in view of the soluble and plastic nature of the beds the junction is often not clearly exposed. There seems little doubt that the oil-shale stage is a part of the Punjab Saline series. At the outcrop, the grey and greenish shales of the stage admittedly have a very young appearance, but this is to a large extent the result of weathering. When newly-exposed, they closely resemble in texture certain of the beds of the *Neobolus* Shales or of the basal part of the Salt Pseudomorph series of the Chittidil locality.

(5) *The Khewra area* (Sheet No. 43 $\frac{H}{2}$).

(See Plates, 4, 5 and 17).

Anderson's 'fossil' locality in the eastern side of the Khewra gorge was again examined and samples taken of the bituminous shales (up to a few inches

thick) that occur within the Upper Gypsum-Dolomite stage. In this gorge-section, the junction between the Punjab Saline series and the overlying maroon shales and flags of the Purple Sandstone series is admittedly disturbed, a small shear-fault being seen traversing also the lower beds of the latter series.

In the Billianwala tributary which forms a gorge running westwards just south of the Mayo Salt hill, the sub-Recent clays, gypseous conglomerates, and soft sandstones, within which plant-remains occur were also examined. These beds dip in the same northerly direction as the near-by salt and gypsum of the Punjab Saline series and, were they to continue to the dip, they would underlie the salt-bearing sequence of the salt mine and probably overlie the lower gypsum-anhydrite-dolomite beds. There is no doubt about these clays, soft sandstones and gypseous conglomerates being of sub-Recent age, tilted during the final earth-movements that affected the outer slopes of the area. They could certainly be the source of the sand and clay intercalations met with in the lower gypsum-dolomite sequence (exposed in the New Low Level Tunnel). Might not percolating water, seeping gradually through this sub-Recent sequence, have carried microscopic, buoyant plant-fragments into the adjoining Saline series of the Salt Mine hill to the north and of the gypsum hill to the south at a time when the Salt Range was, relative to the alluvial plains, at a lower level and the ground-water table correspondingly higher.

While at Khewra, Mr. B. S. Lamba showed us the salt, gypsum, and dolomite cores that had been obtained from the Saline series sequence in a bore-hole put down below the Pharwala seams in the Mayo Salt Mine. The indications of oil in the gypsum were of much interest. The detailed sequence will no doubt be given in Mr. Lamba's contribution to this Symposium.

Other bore-holes put down at the southern toe of the gypsum hill, east of the entrance to the New Low Level Tunnel, passed through gypsum and gypseous marl into sub-Recent conglomerates and talus containing boulders of Eocene limestone and Magnesian Sandstone.

(6) *The Kallar Kahar area* (Sheet No. 43D₉).

From Khewra, a visit was paid to Kallar Kahar on the Salt Range plateau, where Mr. Lamba had reported the occurrence of the Salt Marl overlain conformably by the Laki limestones. It may be pointed out that, for the Punjab Saline series to be homotaxial with the saliferous sequence of Kohat, it would have to *overlie* the Eocene of the Salt Range. The evidence at Kallar Kahar

is certainly against its occurrence immediately beneath the Laki sediments, and is also against it being post-Laki in age.

In my opinion, the Salt Marl exposures near Kallar Kahar yield no evidence of the exact age of the series. There is good reason to regard the occurrences of that locality as having arrived at their present position as a result of intrusion upwards along a zone of faulting. This fault-zone continues E.S.E. and links up with the faulted anticline of the Nawabi Kas to the west of Makrach, within which the Punjab Saline series is well-exposed beneath the Purple Sandstone series. Northwest of Kallar Kahar, this fault-zone continues for some distance among Lower Siwalik strata.

(7) *The Jalalpur area* (Sheet No. 43 $\frac{H}{6}$).

(See Plates 1, 4, 18 and 19).

In the Jalalpur area of the eastern end of the Salt Range, particular attention was paid to the sequence about a mile west of the town where, in the scarp slopes above the village named Chitti, the sequence embracing the Upper Gypsum-Dolomite stage of the Punjab Saline series, the Purple Sandstones and the higher Cambrian beds have been thrust southwards along a low angle fault upon steeply-dipping, reversed, Upper and Middle Siwalik beds. The thrust junction is clearly discordant, cutting across various horizons of the Siwalik sequence and resulting in the brecciation and slickensiding of the sandstones and clays below the thrust-plane.

Above the thrust, the Upper Gypsum-Dolomite stage (of the Punjab Saline series) includes much-jointed dolomite, with very thin intercalations of black shale. The maroon shales and flags (of the lower part of the Purple Sandstone series), which overlie the gypsum-dolomite beds, are usually markedly jointed and veined with fibrous gypsum, and are often contorted and sheared for some distance above the base of the sequence. The section shows clearly the type of disturbance that takes place when definite overthrusting has occurred—that is, the over-riding of the Siwaliks—for only a relatively short distance. Were the Punjab Saline series of Eocene age, involving a thrust of 15 to 20 miles in the same southerly direction, one would surely have expected similar or much greater disturbance.

Up the Kahan (Jalalpur) gorge, the exit of which is just east of Jalalpur town, we observed the 'horst', composed of brecciated remnants of the Punjab Saline series, the Purple Sandstone series and higher Cambrian beds, vertically disposed and traversing the Nimadric sequence. North-east of the gorge, the

strata of this attenuated fault-zone pass into the normal sequence of Chambal ridge, with steep dips to the south-east and east. There, at the top of the Punjab Saline series, the Upper Gypsum-Dolomite stage is represented largely by massive, jointed, light-coloured dolomite, pitted at several horizons; cherty dolomite also occurs. The sequence closely resembles the top dolomite of the Amb and Ratta sections below Sakesar described under (3) above.

Summarised principal results of the October, 1945 excursion.

Briefly, the principal results of this second excursion are:—

- (i) Further evidence of the pre-Talchir age of the Punjab Saline series in the exposures near hill 1127, north-east of Daud Khel in the western end of the Salt Range. Pink gypsum, in all probability derived from the Punjab Saline series of that locality, occurs as pebbles and as one large boulder in the lower part of the Talchir conglomerates.
- (ii) Additional evidence of a normal, undisturbed sedimentary contact between the Punjab Saline series and the overlying Talchirs in the Dhodha Wahan area west of Ratta. Also, we noted the striking similarity in the sequence of beds of the Saline series that underlies the Talchirs of the Ratta area and that lies below the Purple Sandstone series at Amb in the same area. These dolomites and cherty dolomites also closely resemble the beds of the Upper Gypsum-Dolomite stage of the Chambal area, north of Jalalpur at the eastern end of the Salt Range.
- (iii) The close association of the gypsum-dolomite-oil shale sequence of the Warcha-Fatehpur Maira area, substantiating the previously-held view that this stage forms a part of the Punjab Saline series and occurs beneath the middle, Salt Marl stage.
- (iv) The lithological similarity between the red shaly marls and grey-green shales of the Punjab Saline series and certain undisputed Cambrian (or pre-Cambrian) beds.
- (v) The disturbed nature of the junction beds, including the basal Purple Sandstones, near Jalalpur where there is undisputed evidence of a low angle thrust-plane, as compared with an absence of contortion and shearing along this junction in many other areas.
- (vi) The occurrence of thin kerogen shales, yielding appreciable quantities of inflammable gas and oil on distillation, interbedded

with the Cambrian (or pre-Cambrian) dolomites of the upper stage of the Punjab Saline series in the undisturbed exposures near Ratta, below Sakesar. Similar bituminous shales had previously been found elsewhere—at Khewra, near Makrach, etc.—in the same topmost stage of the series.

IV. CONCLUSIONS.

To my mind, the stratigraphical evidence proves conclusively that the Punjab Saline series is pre-Purple Sandstone in age, that is to say, it belongs either to the Cambrian or pre-Cambrian. It is equally certain that kerogen shales, in which the petroliferous content is most probably indigenous, form a part of that series. Percolating ground-water could certainly carry microscopic, buoyant plant-fragments for considerable distances into the readily soluble rock-salt, and possibly into the less soluble gypsum and porous dolomite. It is, however, more difficult to imagine the same phenomenon taking place in the case of the kerogen shales. Either animal or vegetable matter appears to have been the source of the kerogen. We have no evidence of animal remains in these beds, but there is definite evidence of fossil algae and of woody tissue. Can the latter not represent a Cambrian flora; this question has, I understand, also been asked by Dr. G. M. Lees?

To invoke a low angle regional thrust of a magnitude of 15 to 20 miles is contrary to the critical evidence of the normal sedimentary junctions seen, particularly, in the Sakesar area. We have observed that where thrusting has occurred among the Salt Range sequence, it has invariably resulted in junctions displaying visible disturbance of the beds above and below the plane of movement. Thrusting on a limited scale within the Salt Range scarp and also on the plateau to the north is admitted; but the form of the Salt Range and its continuation westwards across the Indus river, together with its more detailed structure can be satisfactorily explained without invoking a regional movement southwards of the whole north-western corner of India lying north of the toe of the Salt Range and its trans-Indus extension.

In favour of the Eocene viewpoint, the two following arguments have often been raised:—

- (a) The relatively recent appearance of the sequence included in the Punjab Saline series and its similarity to the Saline series (Eocene) of Kohat, and
- (b) The improbability of having two saliferous formations of such different ages occurring in relatively close proximity to each other.

Both these points have been previously dealt with by various writers. It is, however, desirable to refer to them again as they have been stressed in recent papers.

Regarding the former (a), it is, I think, admitted that saliferous deposits—rocksalt, saline marl, gypsum and dolomite—often exhibit much the same lithological characteristics whatever their geological age may be. In older deposits of calcium sulphate, one might perhaps expect a greater proportion of anhydrite as compared with the dihydrate. Concerning the clastic sediments of the Punjab Saline series, the kerogen shales (oil-shales) are very definitely shaly in character. It is the non-bituminous, grey and greenish, argillaceous beds of the sequence which, at the outcrop, present a very young appearance. This, I consider, is due to weathering and to the rapid disintegration of the shales near the surface as a result of the crystallisation of salt from solution during the dry, hot weather months and the re-dissolution of the salt particles during periods of rain. As previously mentioned in this note, on excavating a foot or so inside the outcrop, relatively hard shaly-clays and shales are met with, bearing a close lithological similarity to undisputed Cambrian shales of neighbouring sections. Equally closely could one match certain of the shales and flags of the Purple Sandstones and Salt Pseudomorph series with similar beds in the Speckled Sandstone stage (Upper Carboniferous) and even with lower Nimadric (Miocene) types. This feature is doubtless explained by the fact that the Cambrian sequence of the Salt Range has, up to late Tertiary times, never been buried under more than a few thousand feet of younger strata and has thus not been subjected to the higher temperatures met with at deep underground levels. Also, until late Tertiary times, the strata were never subjected to considerable lateral pressures, the stresses involved being sufficient to cause only local warping, admittedly sharp in the Chittidil region during pre-Talchir times. It is, therefore, apparent that the lithology of the sequence met with in the various formations of the Salt Range scarp bears no relation to geological age. From this standpoint, one cannot, therefore, fairly oppose a Cambrian or pre-Cambrian age for the Punjab Saline series, and a lithological comparison with the Eocene saliferous sequence of Kohat bears no weight.

Regarding (b)—the improbability of having two saliferous formations of such different ages occurring in such close proximity to each other—this becomes much less of a coincidence when one notes the geological history of the Salt Range—Potwar—Kohat region.

It is recognised that in the northern parts of the Peninsula during Upper Vindhyan times (Cambrian or pre-Cambrian), shallow-water marine conditions accompanied by an arid climate prevailed, resulting in actual deposition of gypsum at least in parts of Rajputana. About the same time, similar conditions existed in the Salt Range and trans-Indus areas depositing, apart from the Punjab Saline series, the Purple Sandstone beds. During later Cambrian times, the fossiliferous *Neobolus* Shales and the Magnesian Sandstones were laid down and were followed by the Salt Pseudomorph series. Within the argillaceous sediments of the latter, cubical crystals of common salt and minor bands of gypsum were initially deposited in the Salt Range region. These strata all bear witness of shallow water marine conditions with a high degree of salinity at least during the later Cambrian. Still more convincing proof of the existence of conditions favouring the formation of saliferous deposits at that time is seen in the Khasor Range, near Saiduwali, where alternating gypsum (with anhydrite) and dolomite occurs, several hundred feet in thickness, within the upper Cambrian sequence. Interbedded shales with salt pseudomorphs are also reported (by Mr. Pinfold). It is apparent, therefore, that during Cambrian (and late pre-Cambrian) times, conditions favouring the formation of salt, gypsum and dolomite prevailed periodically in parts of northwestern India. The occurrence of a Cambrian (or late pre-Cambrian) saline series in the Salt Range area is, therefore, not surprising.

From the late Cambrian onwards, until the late Palaeozoic, the above-mentioned shallow sea (the Tethys) retreated northwards to beyond the Salt Range area. From the Upper Carboniferous until late in the Eocene, the position of the coast-line of the Tethys fluctuated periodically along a N.-S. or N.W.-S.E. line, marine waters sometimes extending southwards across and beyond the Salt Range area and, at others, retreating northwards towards the present Himalayan region. Would it be surprising if areas of salt water were isolated in separate shallow basins during these fluctuations? Might one not have expected that evidence of marine desiccation would be apparent at other periods besides the Cambrian and Eocene? No one comments on the occurrence of lateritic deposits at several horizons in the Salt Range sequence,—during the Trias or early Jurassic, again later in the Jurassic and again during the Cretaceous-Tertiary interval; yet such deposits imply a repetition of special climatic and topographical conditions.

In my opinion, bearing in mind the geological history of the northwestern corner of India, it is not a strange coincidence to find three saliferous series—

one early Cambrian or pre-Cambrian, the second late Cambrian, and the third Eocene (basal Khirthar)—included within the stratigraphical sequence of the Salt Range and adjoining regions. In this connection it may be mentioned that, in neighbouring areas in the southwestern Punjab and in Baluchistan, massive gypsum occurs among the shallow water, limestone-shale, Khirthar sequence, indicating a fourth phase of marine desiccation in north-western India during the course of its geological history.

V. SUGGESTIONS REGARDING FUTURE RESEARCH.

Regarding lines of future research, the determination of the age of the Khewra trap on the basis of its lead-uranium ratio is, of course, important. As regards the application of the magnetic orientation of the mineral grains in the clastic sediments above and below the supposed regional thrust-plane, it seems very doubtful whether suitable material can be obtained from the Punjab Saline series, even were the method otherwise reliable.

Concerning future palaeobotanical research, Prof. Sahni will, I hope, forgive me if I make a suggestion. The separation and determination of further organic remains from the various rocks of the Punjab Saline series, particularly from the kerogen shales is, of course, important. But, if palaeobotanists are agreed that the plant-‘fossils’ cannot represent a newly-discovered Cambrian (or late pre-Cambrian) flora, then I would suggest that steps be also taken to find out the means by which this micro-flora became embedded in the rocks in question. This would no doubt require much painstaking laboratory work on test-samples whose age is undisputed; but such a task is obviously very necessary.

Dr. Crookshank has also verbally raised the question as to whether the Neobolus Shale fossils indicate an undoubted Cambrian age, or whether they might not represent a fauna which has survived into somewhat later, say Ordovician, times. This point I am referring to the palaeontological specialists*.

In conclusion, I would like to make one final proposal. In spite of the very pleasant conditions under which this meeting is being held, should it be decided that a third symposium is desirable, then I consider that its *venue* must be the Salt Range itself, preferably the Warcha-Sakesar area. The authors in this controversy are—

* Prof. W. B. R. King has since informed me that the Neobolus Shales are either highest Lower Cambrian or lowest Middle Cambrian in age.

- (a) supporters of the Cambrian view; who include all those field-geologists who have examined the critical sections on the ground, and
- (b) supporters of the Eocene view, none of whom—excluding Prof. Sahni—have seen these critical sections, but who either base their views largely on the examination of exposures in the Khewra and Warcha gorges or, not having been fortunate enough ever to visit the Salt Range, submit interesting dissertations based largely on regional data and suppositions. Agreement will not be reached by pursuing this procedure further; only by examining the stratigraphical sections on the ground can one realise their significance. I would earnestly request those who hold the Eocene view to visit the Salt Range, and for their guidance I propose, as an Appendix to this paper, to include in the published results of this meeting, details of suggested tours.

Postscript:—Since this contribution has gone to the press, my attention has been drawn to the following important paper on the Salt Range by Prof. K. K. Mathur and Mr. M. P. Bajpai, entitled “The Geology of the Chhidru Hills, Salt Range” and published in the *Quarterly Journal of the Geological, Mining and Metallurgical Society of India*, Vol. II, No. 3, September, 1929. (*E. R. Gee*).

VI. APPENDIX.

SUGGESTED GEOLOGICAL TOURS.

Geological tours are suggested in the following areas:—

- I. Khewra—Dandot—Choa Saidan Shah area (Sheets 43 D/13 and 14 and 43 H/1 and 2).
- II. Jalalpur area (Sheet 43 H/6).
- III. Nurpur—Vasnal area (Sheet 43 D/10).
- IV. Warcha—Chittidil area (Sheets 38 P/14 and 15).
- V. Nammal Gorge—Buri Khel area (Sheets 38 P/10 and 14).
- VI. Daud Khel area (Sheet 38 P/9).
- VII. Mari Indus—Kalabagh area (Sheet 38 P/9).

I. *Khewra—Dandot—Choa Saidan Shah Area*

(Sheets 43 D/13 and 14 and 43 H/1 and 2).

(The area is reached by train to Khewra, N.W.R., or alternatively to Chakwal and thence by lorry road to Choa Saidan Shah (20 miles), and on to Khewra (14 miles). Permission to occupy accommodation at the Circuit House, Khewra and at the Rest House, Choa Saidan Shah can be obtained on application to the Administrative Officer, Central Excise and Salt, P. O. Khewra, District Jhelum, and to the Deputy Commissioner, Jhelum, respectively.)

Much of the area in question is covered by the geological map (Scale one inch=one mile) included as Plate 2 of my paper published in the *Proceedings of the National Academy of Sciences, India*, 1944 (issued Allahabad, 12th June, 1945).^{*} The sequence exposed is shown in Text-fig. 2 of the above publication and in Plate 4, Fig. 3 and Plates 5, 6 and 17 of this contribution. It includes:—

^{*}Obtainable from the General Secretary, National Academy of Sciences, Department of Botany and Geology, University of Lucknow, United Provinces. Price including postage: Rs. 4-8/- (India) Rs. 5/- (Abroad).

<i>Nimadric Formation.</i>	{	Siwaliks and	
Miocene to Pliocene 26 to 29).*		Upper Murrees	.. 10,000 ft. (approx.).

(Unconformity)

<i>Lower Nummulitic Formation</i> Eocene (17 to 22).	{	22. Bhadrar beds—0-100 feet	
		21. Sakesar limestone	
		20. Nammal limestones and shales.	250-300 feet
		19. Patala shales (including Dandot coal seams)	.. 50 feet
		18. Khairabad limestones	.. 0-20 „
		17. Dhak Pass beds	.. 10-25 „

(Unconformity)

Upper Carboniferous	{	8. Speckled Sandstones	.. 150-300 feet
		7. Conularia beds	.. 50-75 „
		6. Talchir Boulder-beds	.. 2-30 „

(Unconformity)

Cambrian	{	5. Salt Pseudomorph beds	.. 0-100 feet
		4. Magnesian Sandstones	.. 100-250 „
Cambrian or pre-Cambrian.		3. Neobolus Shales	.. 120-150 „
		2. Purple Sandstone series	.. 300-400 „

(Junction disturbed in some places,
conformable and undisturbed
contact in others)

Cambrian or pre-Cambrian	{	1. Punjab Saline series.	
		(c) Upper Gypsum-Dolomite stage	.. 10-75 feet
		(b) Salt Marl stage upto to	800 feet
		(a) Lower Gypsum-Dolomite stage—(several hundred ft.)	

(Base of the Punjab Saline series is not exposed).

The type area of the Punjab Saline series is the vicinity of the Khewra gorge around Khewra. The Purple Sandstone series and overlying Cambrian beds, together with the Upper Carboniferous sequence are well exposed in the scarp slopes just north of Khewra and north-west of Dandot Railway Station; also on the plateau area in the Gandhala valley and in the western slopes of

*These numbers correspond to those given in Table 1 of the publication above-mentioned.

Karangal mountain to the southwest and northeast, respectively, of Choa Saidan Shah. A portion of the Eocene sequence crops out in the Khewra gorge near the water supply reservoir and in the lower part of the Dandot gorge about $1\frac{1}{4}$ miles W. by N. of Dandot Railway Station. The best exposures are, however, at the top of the scarp around Dandot village, also in the Pidh and Choa Saidan Shah areas on the plateau. Bhadrar Beds occur on the Eocene limestone plateau north and west of the latter area and clear sections are seen further north in the slopes overlooking Dhok Tahlian.

Brief descriptions of the various strata have already been included in Table 1 of the above-mentioned published paper.

The following geological tours are suggested:—

- (A) Khewra Gorge section.
- (B) Mayo Salt Mine and adjoining areas.
- (C) Dandot Gorge section.
- (D) Choa Saidan Shah—Karangal area.
- (E) Dhok Tahlian area.

— (A) *Khewra Gorge section*—(Sheet 43 H/2).

(See Plate 4, Fig. 3 and Plate 17).

At the entrance to the gorge on the west side, the Purple Sandstone—Neobolus Shale—Magnesian Sandstone sequence forms hill 1817, on which the *old* Circuit House (of the Salt Department) is situated. Around these slopes extensive slips have taken place obscuring the *in situ* succession. A well-marked fault, almost vertical, brings in the Saline series to the north while on the eastern side, hidden by the alluvium of the Khewra gorge, a N-S displacement separates this Cambrian succession from the Saline series (Lower Gypsum-Dolomite stage) of the Eastern Hill.

This Eastern Hill together with the Mayo Salt Mine Hill and Bhandar Kas area to the north is one of the type areas of the Punjab Saline series and includes the three stages tabulated above. The structure is complicated; it is briefly described under (B) below. The general dip is northerly.

About two miles up the gorge from Khewra Railway Station, the Saline series is overlain by the Purple Sandstones and higher Cambrian beds, all very clearly exposed dipping northwards (upstream) at moderate angles. The sequence is as follows.

Above the Upper Gypsum-Dolomite stage (of Anderson's fossil locality $\frac{1}{2}$ -mile upstream from the junction with the Bhandar Kas tributary), typical maroon shales and flags of the lower part of the Purple Sandstone series crop out. In the gorge section, these basal shales and flags are disturbed, a local inclined fault being clearly exposed within the sequence in the left side of the gorge. The passage up from the maroon shales and flags into the massive maroon and buff sandstones of the upper part of that series is fairly sharp but conformable. There is no doubt that the shales and flags of the lower part of the sequence and the predominantly massive sandstones of the upper part comprise one series, laid down under similar conditions in a shallow sea. As we go up through the series, the change is merely one of lithology indicative of predominantly argillaceous sedimentation in the early stages which gave place, without interruption, to predominantly arenaceous deposition during later Purple Sandstone times. The general red colour of the strata indicates a prevalence of arid conditions during that period whilst current-bedding, repeated ripple-marking and the evidence of sun-cracks are clear indications of shallow-water deposition. Throughout the eastern and middle-western portions of the Range between Jogi Tilla and Chhidru, a distance of over 100 miles, the Purple Sandstone series presents the same lithological characteristics and can, without exception, be divided into the two well-marked stages, conformable with each other and to a greater or less extent transitional. Only in the Jogi Tilla area does one find a conglomerate bed incorporated in the upper, sandstone stage; in other places the sequence continues with monotonous regularity though varying somewhat in thickness from one place to another. The sea-floor during those times (pre-Cambrian or early Cambrian) was, therefore, extremely regular and, throughout the period, gradual subsidence must have prevailed. No recognisable fossils have been found in the Purple Sandstones. Their lower Cambrian or pre-Cambrian age is decided on the fact that they underlie the fossiliferous (Cambrian) Neobolus Shales, the junction being one of normal sedimentary deposition with no marked unconformity.

Contrasting with the prevalent maroon and purplish-red tints of the Purple Sandstones, the overlying Neobolus Shales present a characteristic grey colour which continues with the same striking regularity. The term 'shales' might be criticised as a misnomer, for the sequence includes only a very small proportion of purely argillaceous beds and is predominantly arenaceous. Impure, often micaceous, sandstone and argillaceous sandstones, alternating rapidly, comprise the greater part of the series, specks of dark green (almost

black) glauconite being characteristic of many of the beds. In the upper part, beds of hard dolomitic sandstones occur indicative of the change in sedimentation which gave rise to the succeeding Magnesian Sandstone series.

One of the most characteristic horizons of the *Neobolus* Shales is, however, the basal conglomerate which, in lithology and occurrence, persists with remarkable regularity. This bed, now closely cemented on to the top surface of the Purple Sandstones, is usually only a foot or so in thickness. In lithology, it consists mainly of oval-shaped and flattened pebbles of dark grey semi-quartzite and hard sandstone, and also of slate embedded in a quartzitic matrix of fine to coarse sand, light yellow to buff in colour, the grains and small pebbles being well-rounded. The pebbles of semi-quartzite, slate etc. usually vary up to a few inches in length. Apart from the characteristic dark grey and greenish-grey colour of the main sequence, occasional dark red and maroon sandstone bands occur in the lower part of the series. Shallow-water conditions of deposition are indicated not only by the occurrence of glauconite and the admixture of sand and clay in the various strata but also by the ripple-marking of certain of the sandstones.

Fossil contents include numerous, rather indefinite, annelid markings together with easily recognisable brachiopods (*Neobolus Warthi*) of primitive type and less frequent trilobite fragments (*Redlichia*, *Ptychoparia*, etc.) The latter occur mainly in the upper, argillaceous beds. In the Khewra gorge section, trilobite remains are difficult to find but a number of specimens of *Neobolus* occur in the shales a short distance below the top of the series. The chitinous shells are preserved, usually as separate valves, almost circular in outline and about $\frac{1}{4}$ inch in diameter. Being usually of greyish colour, these fossils are at first somewhat difficult to spot but, once recognised, additional specimens are readily located. The fauna is described in a paper entitled 'Cambrian Fauna of the Salt Range of India' by W. B. R. King [*Rec. Geol. Surv. Ind. Vol. LXXV, Prof. Paper No. 9, (1941)*].

The fossiliferous *Neobolus* Shales are conformably overlain by the Magnesian Sandstones, which form steep cliffs on the west side of the Khewra gorge (below Tobra village) and also on the east. These two series are quite conformable and easily recognisable throughout the eastern part of the Salt Range. They indicate continuous marine sedimentation during Cambrian times with merely a change from arenaceous—argillaceous to arenaceous—calcareous and dolomitic conditions. The strata of the Magnesian Sandstone series vary from calcareous and dolomitic sandstones of fine texture to fairly pure dolomites.

All are well-jointed and are of light-grey, cream or greenish-grey colour; glauconite occurs as small grains in the latter. Certain horizons within the series show a concretionary (pseudo-pisolitic) structure, the pisolites usually having a maximum diameter of about $\frac{1}{2}$ inch; other bands are micaceous.

In the gorge-section, the Magnesian Sandstones are well-exposed and are overlain conformably by the flaggy, dark red sandstones and shales of the Salt Pseudomorph series—the uppermost member of the Lower Palaeozoic, sequence of the Salt Range. The latter are well-exposed in the western side of the gorge a short distance below that ‘rift’ of white Eocene limestones, downstream from the Salt Department water-reservoir. Only the lower beds of the Salt Pseudomorph series occur, the higher strata having been eroded away from this locality in later Palaeozoic times before the deposition of the Talchir Boulder-beds (Upper Carboniferous). Excellent examples of ripple-marked flags and of cubic-shaped salt pseudomorphs are, however, seen among the beds represented. There is no reason to assume that these pseudomorphs do not actually represent crystals of common salt that crystallised out in the shallow, dessicating sea at the time of deposition of the flags and shales and which were redissolved by the marine waters and replaced by casts of mud. The junction between these Salt Pseudomorph beds and the overlying Talchirs provides an excellent example of an erosive unconformity. Traced to the east and west of the Khewra gorge, the Salt Pseudomorph beds vary appreciably in thickness. The series was obviously uplifted and exposed to irregular denudation during the time-interval preceding Talchir deposition.

Just beyond the exposure of the Talchirs in the left side of the gorge, a few hundred yards downstream from the water-reservoir, a steeply inclined fault-plane cuts across the gorge in a N.E.-S.W. direction bringing down steeply-dipping Eocene limestones against the Talchir conglomerates and the underlying Salt Pseudomorph strata. The Eocene limestones (Sakesar and Nammal stages) actually form a narrow, faulted syncline—a ‘rift’ structure—the north-western limb of the syncline extending up to the water-reservoir. Beyond the latter, the Talchir conglomerates are again well-exposed in the gorge-bed. They are dark-coloured and include typical boulder-beds with grit bands. The boulders, consisting largely of quartzites, granitic rocks and some reddish-brown rhyolites, etc. are often polished and vary from rounded to sub-rounded and faceted types. Occasionally, scratches denoting ice-action during Talchir times are observed on the facets. The gritty and sandy matrix includes granitic fragments and fresh felspar grains showing an absence of chemical weathering during that period.

Higher up the valley beyond the reservoir and in the adjoining slopes, the Talchir Boulder-bed is overlain by green-grey sandstones and shales (with thin carbonaceous intercalations) belonging to the *Conularia* stage; the latter pass upwards into the reddish, green and grey sandstones and shaley clays of the Speckled Sandstone sequence. This series and the overlying Eocene limestones with the Dandot coal seam at the base is well-exposed up the western slopes about $\frac{1}{2}$ -mile west of the reservoir. Further details of the Upper Carboniferous and the Eocene strata are given under (C) and (D) below.

Regarding the Khewra gorge section, the synclinal rift of Eocene limestones occurring just downstream from the reservoir is a typical faulted structure, the crushed and sheared fault zones adjoining the actual planes of displacement being clearly exposed and marked by slickensiding especially on the south-eastern side. The light-coloured limestones are largely nodular to semi-nodular in type and contain numerous foraminifera together with a well-marked oyster-bed at the base—exposed in downstream limb of the syncline on the left side of the gorge. Within the syncline, resting on the Eocene limestones, green-grey sandstones with red and green clays occur; these beds represent a remnant of the Lower Siwaliks which, at the end of the Tertiary period, extended southwards from the Potwar and covered the whole of the Salt Range region.

A geological section up the Khewra gorge is included as Plate 4, Fig. 3. Approximate thicknesses of the strata are given in the stratigraphical sequence listed above.

(B) *Mayo Salt Mine and Adjoining Areas.* (Sheet 43 H/2)

(See Plate 4, Fig. 3, Plate 5 and Plate 17).

The Punjab Saline series is well-exposed on both sides of the Khewra gorge; the detailed sequence is, however, displayed more clearly in the eastern slopes including the Eastern (Gypsum) hill, the Mayo Salt Mine to the north and the area around the Bhandar Kas still further north. In general, the dip is northerly at varying angles; in addition, the sequence is duplicated by a fault running E.—W. approximately along the Bhandar Kas. As a result, the Lower Gypsum-Dolomite stage occurs in the Eastern hill and again around the Bhandar Kas, and the Salt Marl stage of the Mine Hill is similarly repeated in the steep slopes north of the Bhandar Kas. Remnants of the Upper Gypsum-Dolomite stage are seen at intervals to the south-east and east of the Salt Mine Hill, but the best exposure is in the repeated sequence in the Khewra gorge at Anderson's fossil locality, just below the outcrop of the Purple Sandstones. A section

drawn N.—S. across the area is included as Plate 4, Fig. 3. In addition to excellent exposures of the Saline series, the area affords clear evidence of the intimate association of sub-Recent sands, clays and conglomerates with that series; these occurrences are also described below.

In the Eastern (Gypsum) Hill, the Lower Gypsum-Dolomite stage is well exposed in the southern slopes and also in the New Low-Level Tunnel (now being excavated). The 'gypsum' actually consists usually of a mixture of the dihydrate and anhydrite and forms several thick seams light to dark grey in colour alternating with dull red marl, flaggy, jointed dolomite (sometimes slightly bituminous and giving off a foetid smell when freshly broken with the hammer) and mixtures of gypsum and dolomite. Irregular bands and lenticles of soft brown sandstone, probably of sub-Recent age, are met with in the sequence traversed by the tunnel. The strata show considerable disturbance due to the following combination of events—late Tertiary to sub-Recent tectonic movements resulting in folds and faults; slumping, especially near the outcrops; pressures set up as a result of chemical changes (*e.g.* anyhydrite to gypsum) which are accompanied by changes in the volume of the rocks involved. Above this gypsum-dolomite sequence to the east of the Gypsum Hill, the higher stages of the Saline series—bright red Salt Marl, and Upper Gypsum-Dolomite beds—are observed, underlying the maroon shales and flags of the Purple Sandstone series. The Salt Marl stage is however, much attenuated in these sections, the included rocksalt having, apparently, been largely removed by solution.

The Salt Marl, stage of the Khewra (Mayo) Salt Mine includes the under-noted sequence. For those who wish to study the seams within the mine, a geological plan is included as Plate 5, Fig. 1. During recent years, the workings have extended eastwards beyond the limits included in the latter. A section through the workings is also given (*see* Plate 5, Fig. 2).

Sequence exposed in the Mayo Salt Mine, Khewra.

(Marl).

North Buggy Seam—This name has been given, by the mining staff at Khewra, to a seam of workable rock-salt, ? 25 to 50 feet thick, occurring in certain of the northernmost workings of the middle and middle-eastern parts of the mine.

(Marl.—? up to 10 feet.)

Buggy Seam—In the western end of the mine, the Buggy seam, including several bands of marl and *kallar*¹ (usually only a few feet thick) is nearly 200

¹ *Kallar* is a local name given to very impure salt and saline marl.

feet in total thickness. It consists largely of good workable salt. Correlating the uppermost marl bands as far as is possible on the evidence available, it appears that the seam decreases to 140-170 feet in the middle portion of the mine, and it possibly thins further to 120 feet around Chamber 35.

In the north-eastern workings, the upper part of the Buggy is affected by an inclined shear-fault, but a 65—to 80-foot section of the lower part of the seam has been proved to continue and to include very good quality salt.

(Buggy-Sujowal Marl.—In the extreme western part of the Mayo Mine, and in certain of the north-eastern chambers, the marl separating the Buggy seam from the underlying Sujowal seam is absent, or limited to a few feet. It is, however, more regular in the middle portion of the workings where it usually varies up to about 15 feet in thickness but is occasionally as much as 30 feet).

Sujowal Seam.—The Sujowal seam varies from 60 to 80 feet in thickness in the western workings. In the middle part of the mine it is 50 to 65 feet thick, but in many of the eastern workings it thins to about 30-35 feet including a 6 foot band of marl in the middle. This marl appears, however, to die out in the south-eastern, recently-developed workings (Pharwala Development Chamber 40) where the seam has thickened to at least 50 feet. On the whole, Sujowal salt is of good workable quality.

(Sujowal-Pharwala Marl.—Marl, followed below by alternating thin seams of salt, marl, and kallar, underlies the Sujowal seam. One seam is of workable thickness in the western part of the mine. In the western part of the mine, this sequence is not more than 60 feet thick, but east of Chamber 24 it reaches as much as 100 feet.)

Upper Pharwala Seam.—This seam, usually about 35-50 feet thick, is of moderate to poor quality. The seam is appreciably thicker than 50 feet in the middle part of the mine. It usually includes some 'potash' salts intermixed near the bottom of the seam.

(Upper Pharwala-Middle Pharwala Marl.—In the western part of the mine, the marl and kallar between the Upper and Middle Pharwala seams is often not more than 20 to 40 feet thick but includes a local seam of salt upto 50 feet thick. From Chamber 15 onwards this seam thins rapidly and the marl thickens appreciably; in the eastern part of the mine this marl is as much as 60 to 70 feet thick).

Middle Pharwala Seam.—This seam is of very poor quality in the extreme western workings, but from about Chamber 8 eastwards it becomes important.

It is about 70 to 80 feet thick at the main level (the Low Level—South Pharwala area) but appears to thicken appreciably to the dip. It includes a few thin bands of kallar and marl, one fairly regular band up to about 9 feet in thickness occurring in the middle-lower portion of the seam.

Possibly, it is the salt beneath the latter band of marl that is sometimes designated the 'Lower Pharwala' seam.

Gypsum, dolomite and marl of the Lower Gypsum-Dolomite stage has been met with in a bore-hole sunk below the Pharwala seams (*see* paper entitled "Note on Cores from a Bore-hole in the Mayo Salt Mine, "Khewra" by Mr. B. S. Lamba).

The salt deposits of the Mayo mine form the north-eastern quadrant of an irregular dome. On the north side of the Salt Mine hill, the salt deposits usually dip northwards at steep angles and are then cut off by the above-mentioned steeply-inclined shear-fault that runs east-by-north up the Bhandar Kas. This shear, or at least a subsidiary fault-plane associated with this zone of tectonic movement, cuts out the uppermost salt-bearing strata of the north-eastern corner of the mine where it has been exposed in the higher levels. Saline water, fortunately in limited quantity, finds its way into the mine along this shear zone.

As previously mentioned, this thrust-fault repeats the Saline series in the area around and north of the Bhandar Kas, immediately to the north of the Salt Mine hill. Massive gypsum with dolomite and grey-green and red clay-shales belonging to the repeated Lower Gypsum-Dolomite stage crops out in the Bhandar Kas and in the lower slopes to the north whilst the overlying Salt Marl with rocksalt is well exposed higher up those slopes and has been explored to a limited extent just east of the Khewra gorge. So far, the rocksalt proved in these exploratory workings is of considerable thickness but is not of the high quality of the seams of the Mayo Mine. Exploration to the dip may reveal seams of purer quality.

Regarding the Upper Gypsum-Dolomite stage, the best section in this area is the one exposed in the left side of the Khewra gorge below the Purple Sandstones upstream from the junction with the Bhandar Kas. This is the locality from which Anderson collected the leaf-impression identified as a species of *Quercus*¹. The sequence is somewhat disturbed.

¹ See Anderson, R. van V., 'Tertiary Stratigraphy & Orogeny of the Northern Punjab'.
Bull. Geol. Soc. Amer., Vol. 38, p. 665, (1926).

It includes a sequence of dolomite-gypsum beds in which a thin band of black, bituminous shales is intercalated. Khewra trap also occurs within the stage in this section.

Regarding sub-Recent beds closely associated with the Saline series, these are best seen in the tributary *nalas* traversing the Lower Gypsum-Dolomite stage of the foothills just east and south-east of the New Low-Level Tunnel, and also in the Billianwala *nala* which flows southwestwards and westwards just south of the Salt Mine Hill. In addition to the apparently sub-Recent sands and clays that have found their way down into the gypsum-anhydrite beds as exposed in the New Low-Level Tunnel, bands and irregular intercalations of grit and conglomerate containing fragments and boulders of gypsum, dolomite, Purple Sandstone and other Palaeozoic rocks of the vicinity occur dipping at steep angles, the latter now appearing to be interbedded with the gypsum and dolomite of lower part of the series. These beds are well-exposed in the above-mentioned tributary *nalas*, particularly in the one which runs westwards and joins the Khewra gorge about 200 yards east of the junction with the New Low-Level Tunnel.

In the Billianwala gorge north of the Gypsum Hill, similar sub-Recent grits, sandstones and red clays with carbonaceous woody fragments occur, dipping at moderate to steep angles to the north (*see* Plate 17, Fig. 2). Higher up these slopes in close association with the red Salt Marl, bands of red clay with similar woody fragments are met with. In addition, in the Mayo Salt Mine, at the higher levels of the north-eastern corner of the mine, thin bands of red clay and Kallar containing carbonised woody fragments occur among the salt-bearing sequence in close association with the above-mentioned thrust-fault which repeats the Saline series north of the present mine.

Apart from the above, there are, of course, the minute plant—and animal-remains discovered by Prof. Sahni in the salt, *kallar*, dolomite, etc. and described in detail in this Salt Symposium series.

One other feature of interest in connection with the study of the Saline series may be mentioned—namely, the reconsolidation of fragmentary rocks *It* and *kallar* to form seams of banded salt when exposed to alternating damp and dry climatic conditions. This is well observed in the dumps of waste salt and Kallar near the salt-loading depot at Khewra, reconsolidation by partial solution (during periods of rain) and recrystallisation during subsequent periods of drought) having occurred in parts of these dumps within the past few decades.

(C) *Dandot Gorge section.* (Sheet 43 D/14).

(See Plate 6, Fig. 1, and Plate 15, Fig. 2).

The particular section to be visited is in the vicinity of the *nala* which, commencing in the scree covered slopes south-west of Dandot village, runs in a general south-easterly direction and makes its exit on to the plains through a narrow gorge traversing the Lower Gypsum-Dolomite stage about $\frac{1}{2}$ mile west of Dandot Railway Station. The section is representative of the geology of the scarp-slopes south of Dandot plateau and includes an interesting overfold in which the whole stratigraphical sequence of the area is involved. The scarp in question is shown in Plate 15, Fig. 2 below. A section was included as Plate 4, Fig. 2 of my contribution to the 1944 Symposium. This longitudinal, folded structure represents one of the several instances of overturning and duplication observed in the Salt Range scarp, formed as a result of tectonic pressures acting in a N.-S. direction. In many places along the Salt Range, these folds take the form of simple anticlines and synclines, in other sections they are overfolded or pass laterally into fold-faulted structures the various components of which have been thrust one over the other to a limited extent.

Following the Dandot gorge-section upstream, steep cliffs composed of the gypsum-dolomite-marl beds of the lowest stage of the Punjab Saline series are met with for a distance of about half a mile. In general, the dip is at a steep angle to the north-west. Beds of brecciated gypsum and dolomite and of gypseous conglomerate are included in the sequence. In intercalations of sub-Recent and Recent sands, clays and gravels also occur. In the gorge-section, the Salt Marl and Upper Gypsum-Dolomite stages of the series are largely cut out, probably by a strike-fault and, where representatives of these stages might be expected, Recent scree forms the steep slopes of the gorge. A hundred yards or so downstream from the *lower* coal locality (where small coal-workings occur), a portion of the Purple Sandstone sequence crops out dipping steeply upstream. A strike-fault of considerable throw separates these massive, maroon, jointed sandstones from the Tertiary beds (mainly Eocene limestones with coal-shales) which come in upstream and which represent the younger strata involved in the overturned (reversed) limb of the overfold. Associated with these Eocene limestones and shales (Laki and Ranikot) are small occurrences of green-grey sandstone of Siwalik type containing traces of oil.*

As is to be expected, the Tertiary and older strata in the vicinity of this fault-zone are much disturbed, dips vary considerably and local faults and

* See paper entitled 'Note on a Section in the Dandot Gorge' by N. L. Sharma [*Proc. Nat. Acad. Sciences, Ind., Vol. 14, Sect. B. Pt. 6, pp. 259-260, (1945)*]

slickensiding are apparent especially in the carbonaceous shales and marls of the Ranikot. Upstream, the older beds of this reversed sequence (forming the overturned limb of the fold) dip more regularly to the north-west at moderate angles. The gradient of the *nala*, where it now traverses the overturned sequence steepens considerably and large boulders of Eocene limestone which have rolled down from the Dandot cliffs obstruct the route; a way can, however, be found without much difficulty.

Just beyond the lower coal locality, green and dark red sandstones with clay shales of the Speckled Sandstone and Conularia stages (Upper Carboniferous) crop out, followed above (in reversed order) by the Talchirs. The latter form thick conglomerates, including large boulders of granite, quartzite, etc. well-exposed in the right-hand slopes above the gorge. In this reversed limb of the overfold in the vicinity of the section, the Salt Pseudomorph beds are absent from the sequence, the pre-Talchir unconformity having brought the Boulder-beds into direct sedimentary contact with the Magnesian Sandstones. The latter are also relatively thin as a result of pre-Talchir denudation and in the gorge itself they appear to be cut out altogether by a local fault. In both the eastern and western slopes, however, these massive Cambrian beds together with the old Nelobolus Shales and the Purple Sandstones are well-exposed in reversed order as steep cliffs.

Upstream where the valley opens out, the slopes are covered with Eocene limestone scree and it is necessary to follow up the tributary valley which runs from the E.N.E. in order to examine the axial beds of the overfold. About half a mile up this tributary strike-valley, the duplicated Purple Sandstones, dipping northwestwards at moderate angles, are excellently exposed. The lower, maroon shales and flag stage, resting on the younger massive maroon sandstone stage of the series in the reversed limb of the overfold can here be examined in detail, as also the closely associated gypsum-dolomite sequence, representing the Upper Gypsum-Dolomite stage of the Saline series, that comes in along the fold-axis. These beds dip north westwards at about 40°. As described in my contribution to the 1944 Symposium, the maroon shales and flags show no signs of disturbance even near the junction with the Saline series. They appear to be conformable, maroon shales also occur interbedded in the uppermost gypsum.

A good section of the repeated, normal succession is seen in the higher slopes above this point, thin Salt Pseudomorph shales and flags occurring in the sequence around pt. 1340 (*see* one inch-to-one mile Survey of India Sheet

43 D/14) south-east of Dandot village, whilst the Talchir Boulder bed, *Conularia* stage and Speckled Sandstones (lower portion) cap this hill and continue in the slopes below the Eocene scarp.

Of the Eocene in the Dandot area, the Khairabad limestones are very thin. The succeeding Patala Shales including the Dandot coal seam are usually covered by limestone scree though the coal horizon can be studied in a number of adits. The succeeding Nammal and Sakesar stages, Laki in age, are well represented, but in these parts it is difficult to separate the two. The sequence includes nodular and semi-nodular white and grey limestones with marls totalling about 250 feet in thickness and forming prominent cliffs around the plateau. Chert concretions occur at several horizons in the limestones particularly near the top. The overlying Bhadrar beds appear to be absent.

Regarding the Palaeontology of the Eocene, reference may be made to the following papers:—

- (1) The Eocene of the Punjab Salt Range by L. M. Davies and E. S. Pinfold, *Pal. Ind. N. S.* Vol. XXIV, Mem. No. I, (1937), and
- (2) 'A Contribution to the Molluscan Fauna of the Laki and Basal Khirthar Groups of the Indian Eocene,' *Trans. Roy. Soc. Edin.* Vol. LVIII, pp. 25-92; Pls. I-IV (1931) by L. R. Cox.

(D) *Choa Saidan Shah—Karangal area.* (Sheets 43 D/13 and 14, and 43 H/1 and 2).

(See Plate 6, Figs. 1 and 2).

The southern part of this area is included in Plate 2 of my contribution to the first Symposium. The sequence is similar to that described above in the case of the Khewra and Dandot areas, but in addition Bhadrar beds (Laki) and Lower Nimadric sandstones and clays are represented, the former being well exposed overlying the Sakesar limestones on the plateau areas north and south of Katas, two to three miles west of Choa Saidan Shah. Apart from the Eocene limestone plateau, the sections worth visiting are the slopes around Ratuchha, the Gandhala valley and the *Ratuchha-Pidh area* western slopes of Karangal hill situated south, south-west and north-east, respectively, of Choa Saidan Shah.

On either side of the open valley west of Ratuchha, the sequence down to the Magnesian sandstones is well exposed. The Magnesian sandstones are followed by thin Salt Pseudomorph shales, the latter being overlain by the Upper Carboniferous. Within the *Conularia* stage, fossils including species

of *Conularia* and *Eurydesma* are met with, the latter often occurring in ferruginous concretions in the sandstones above the Talchirs (see Some Fossils from the Eurydesma and Conularia Beds (Punjabian) of the Salt Range by F. R. Cowper Reed, *Pal. Ind. N. S. Vol. XXIII, Mem. No. 1*, 1936). The Conularia stage has also proved fossiliferous further south near Pidh, where about $\frac{1}{4}$ mile south of that village the Talchir boulder beds and overlying Conularia and Speckled Sandstone strata are well-exposed alongside the road. Equally good exposures of these Upper Palaeozoic beds and also of the Cambrian occur in the hill-slopes adjoining the Khewra-Pidh road further south, the Talchir-Salt Pseudomorph unconformity being very clearly seen in several sections a mile or so from Pidh.

Returning to the Ratuchha sections the overlying Eocene can be studied in the higher slopes where near the base, the Dandot coal seam is being worked at a number of places.

The section around Choa Saidan Shah village and down the Gandhala valley to the south-west is of interest in exhibiting a sharp syncline of Eocene and Lower Nimadric (Miocene) strata just east of the Choa Gandhala Valley. Saidan Shah village. Followed south-west down the Gandhala, the north-west limb of this syncline is cut out by a reverse fault which, with considerable regularity, repeats the greater part of the eastern Salt Range sequence in the north-western slopes of the Gandhala. The general dip is north-westerly at moderate angles, Kamlial sandstones and clays overlying the Eocene in the left-hand dip-slopes. These Kamlial beds form several small hillocks in the valley and continue into the basal right-hand slopes where they are intersected by the above-mentioned reverse fault. This thrust-structure, also inclined northwestwards, brings in the topmost beds of the Saline series and the succeeding Lower Palaeozoic, Upper Carboniferous and Eocene strata. Examining the fault closely, one finds at places crushed lenticles of Eocene limestone occurring between the Kamlials and the Upper Gypsum-Dolomite beds of the Saline series, these imbrications being well exposed three to four miles downstream from Choa Saidan Shah. The section across the Gandhala valley is included in Plate 4, Fig. 2 of my contribution to the 1944 Symposium.

Up the open valley north-east of Choa Saidan Shah, the strata are repeated in the reverse direction, that is to say, the older beds, including the Cambrian and Upper Carboniferous sequence, have been thrust northwestwards over the Kamlial strata which crop out in the valley. This prominent line of shearing continues northeastwards

and northwards, increasing in intensity towards Karangal. Opposite Chhumbi village, red Salt Marl capped by the Upper Gypsum-Do'omite stage and succeeded by the Purple Sandstones, etc. come in above the thrust-plane and, dipping southeastwards at about fairly steep angles, have been brought upon steeply dipping to vertical Kamlials. Still further north in the western slopes of Karangal ridge, this thrust-plane is seen to cut across the Lower Siwalik sequence. Higher up the slopes of Karangal ridge, the Purple Sandstones, Neobolus Shales and Magnesian Sandstones are very well developed, whilst in the eastern dip-slopes of the ridge to the northwest of Wahali, the Talchirs, etc. of the Upper Palaeozoic are very clearly exposed succeeded by the Eocene. A motorable road links Choa Saidan Shah with Wahali.

(E) *Dhok Tahlian area.* (Sheet 43 D/13).

(See Plate 6, Fig. 3).

Dhok Tahlian, situated on the southern edge of the Potwar north of Choa Saidan Shah is reached by the Choa-Chakwal motorable road, the distance from Choa being seven miles. A Rest House is situated near the road, permission to occupy accommodation being obtainable from the Deputy Commissioner, Jhelum District, P. O. Jhelum.

The area is of interest in affording excellent sections of the Bhadrar beds (Eocene) and Upper Murrees and Lower Siwaliks to the south and of younger Siwalik strata to the north of Dhok Tahlian.

The strata dip steadily northwards, at fairly steep angles except in the case of the Upper Siwaliks which are usually gently inclined.

The sequence includes:—

Upper Siwaliks (350 feet)—Light coloured soft sandstones and conglomerates alternating with light red, brown and greenish-grey clay. Exposed about two miles north of Dhok Tahlian and in the Chakwal road-section 2 to 3 miles north-west of the village.

Middle Siwaliks (5,150 feet)—Reddish and yellow-brown clays and subordinate light green-grey sandstones (Dhok Pathan stage), succeeded below by massive greenish-grey sandstones with light red and greenish-grey clays (Nagri stage). The basal beds crop out near Dhok Tahlian, the high strata coming in to the north. A strike fault repeats the sequence $\frac{1}{2}$ -mile north of the Rest House.

Lower Siwaliks (Chinji stage) (1,950 feet)—Bright red clays with subordinate sandstones. The sequence crops out immediately south of the

village and is also well-exposed in the road-section from Choa Saidan Shah.

Lower Siwaliks (Kamlial stage) (1,300 feet).—Green-grey and brown massive sandstones, Pseudo-conglomerates and dark red and purple clays. Exposed in the Choa Saidan Shah—Dhok Tahlian road section 3 to 4 miles from Choa; also in the ridges about one mile south of Dhok Tahlian.

Upper Murrees (1,150 feet).—Grey and greenish, massive, fairly hard sandstones, pseudo-conglomerates, and dark red and purplish clay-shales. In field-mapping, it is very difficult to draw a boundary between the Murrees and the overlying Kamlial stage. A basal pebble-bed and grit, composed largely of Eocene limestone pebbles and derived foraminifera rests on the underlying Eocene (Bhadrar Beds).

—Regional unconformity, but locally
conformable)—

Bhadrar beds (Laki). (65 feet).—White, cream and light-grey, porcellanous, bedded limestones followed below by reddish-green and yellow green foraminiferal shales with thin limestones. Grey marly limestones at the base. Well-exposed in the stream-sections about two miles south-by-west of the Rest House.

Sakesar Limestones (Laki).—Grey and white, hard, nodular foraminiferal limestones with more massive, semi-nodular, grey, foraminiferal limestones with irregular chert nodules. These limestones form the dip-slopes of the northern edge of the Salt Range plateau south of Dhok Tahlian.

A description of the area, including a geological map [scale, one inch=4 miles], will be found in the Memoir entitled "The Geology of the part of the Attock District west of long. 72° 45'E" by G. de P. Cotter (*Mem. Geol. Surv. Ind., Vol. LV, Pt. 2, (1933)*).

II. *The Jalalpur Area.* (Sheet 43 H/6).

(See Pl. 1 ; Pl. 4 Figs. 1 and 2; Plate 18, Fig. 1, and Plate 19).

(Jalalpur is reached by the motor road from Haranpur Railway Station, the distance being 15 miles. At the eastern end of the town is an Inspection Bungalow; permission to occupy accommodation can be obtained from the Superintendent of Police, Jhelum. It may also be mentioned that a motorable road with a daily bus service runs from Jhelum to Haranpur *via* Jalalpur).

The Jalalpur area is of particular interest not only in offering facilities for stratigraphical study but also in exhibiting clear exposures of the complex fault-structures that accompany the swinging round of the Salt Range from an easterly to northerly direction.

As regards stratigraphy, the Mangal Dev ridge to the north-west of the town includes a fine section of the Lower Palaeozoic, including Salt Pseudomorph beds in the northern dip slopes. In the Chambal ridge to the north-north-east of Jalalpur, where the strata dip in southeasterly and easterly directions, the upper part of the Punjab Saline series and the overlying Purple Sandstones and Neobolus Shales are again well exposed. Regarding younger strata, the Eocene is completely absent, the area affording an excellent example of the Nimadric transgression across the Lower Palaeozoic. North-west of Jalalpur, in the dip-slopes of the Mangal Dev ridge, lower Nimadrics with a basal conglomerate including Eocene limestone pebbles rest directly on Salt Pseudomorph beds, whilst in the Chambal ridge similar Nimadric strata directly overlie the Neobolus Shales. In these sections of the southern end of the Chambal ridge, the Purple Sandstones show excellent examples of ripple-marking and current-bedding, whilst the new, relatively unaltered, appearance of the overlying fossiliferous Cambrian (Neobolus Shales) is strikingly brought out in the sections where they are directly overlain by the Murree sandstones etc. Both north of Mangal Dev and in the dipslopes south-east and east of the Chambal ridge, the Nimadric sequence is excellently exposed, and includes thick Upper Siwalik strata with conglomerates at the top. The latter is well observed in the ridges just north of the road east of Jalalpur.

For studying the stratigraphy and structure the following two excursions are suggested :

- (F) The scarp slopes of Mangal Dev above Chitti village about one mile W.N.W. of Jalalpur.
- (G) The Kahan Kas section north of Jalalpur and the southern part of Chambal ridge.

Notes on these are as follows :—

- (F) *The Scarp Slopes of Mangal Dev above Chitti village.* (Sheet 43 H/6).
(See Plate 4, Fig. 2; Plate 18, Fig. 1 and Plate 19, Fig. 1).

In this section the Lower Palaeozoic sequence (including the upper Gypsum-Dolomite stage of the Punjab Saline series at the base) is thrust west upon Middle and Upper Siwalik strata, which crop out in the basal slopes of

the scarp. The Siwaliks below the thrust dip vertically or at steep angles and, as the thrust-plane is approached, slickensiding becomes marked. The junction between the Upper Gypsum-Dolomite beds above the thrust and the Siwalik sandstones and clays below it is definitely discordant and attended by brecciation. In places, the maroon shales and flags of the overlying Purple Sandstones are disturbed and veined with selenite. Reversed faulting resulting in repetitions of the Magnesian Sandstones and Salt Pseudomorph beds is also seen along the main ridge one to two miles W.N.W. of Mangal Dev.

(G) *The Kahan Kas section north of Jalalpur and the Southern Part of Chambal ridge.* (Sheet 43 H/6).

(See Plate 4, Fig. 1 and Plate 19, Fig. 2).

Following up the Kahan Kas, Upper Siwalik beds continue for about one mile, the general dip being southerly at steep angles though a local dome structure halfway up the section causes variations in the inclination of the beds. Further upstream, the Middle and Lower Siwalik sandstones and clays crop out either vertically or dipping steeply to the south and south-east about two miles north of Jalalpur. These lower Nimadric beds are followed by a narrow fault zone within which crushed remnants of the Punjab Saline series, Purple Sandstones, Neobolus Shales and Magnesian Sandstones occur (*See* Plate 19, Fig. 2). Against this shear zone to the north-west, the Siwalik and Murree strata of the northern slopes of Mangal Dev abut with marked discordance. The above mentioned fault-zone dies out to the south-west in the eastern slopes of Mangal Dev. To the north-east of the Kahan Kas the disturbance diminishes in intensity and, about half-a-mile north-east of the gorge the sequence becomes more regular and passes into the regular outcrops of the Saline series, Purple Sandstones and fossiliferous Cambrian of the southern end of the Chambal ridge.

Further north in the angle between Chambal ridge and the Mangal Dev area, the structure is also complex. As a result of faulting the Punjab Saline series, including massive dolomite at the top, forms a narrow steeply-dipping outcrop running northwestwards towards Dhok Chanda; steeply-dipping Purple Sandstones and higher Lower Palaeozoic beds form narrow ridges between Dhok Chanda and Chak Shadma. This repetition of the Saline series and Lower Palaeozoic rocks is faulted against various horizons of the Middle and Upper Siwaliks which come in to the south-west. A similar further repetition, the result of reversed faulting is seen along the basal western slopes of Chambal ridge to the west of point 2279.

III. *Nurpur-Vasnal Area.* (Sheet 43 D/10).

(See Plate 7 and Plate 8, Fig. 1).

(A motorable road runs from Chakwal (28 miles) and Choa Saidan Shah (29 miles) to Nurpur. Alternatively the journey may be made by train to Lilla, N.W.R. and thence by camel *via* the Nilawan gorge. Rest-houses of the Central Excise and Salt Department are at Nurpur and near the exit of the Nilawan, 8 miles from Lilla Railway Station. Permission to occupy these rest houses can be obtained from the Administrative Officer, Central Excise and Salt, P. O. Khewra, Jhelum District).

Two tours are suggested from Nurpur:—

(H) The Nilawan gorge to the South,

(I) the Vasnal inlier about 5 miles to the north-west.

(H) *Nilawan Gorge.*

(See Plate 8, Fig. 1).

The section, very clearly exposed in many places, illustrates (a) the unconformable overlap of the Talchir Boulder-bed (Upper Carboniferous) across the Cambrian and (b) the occurrence of the full sequence of the Upper Carboniferous including the Lavender Clay stage overlying the Speckled Sandstone stage. In addition, the in-coming of the Permian is represented by fossiliferous sandstones and sandy limestones belonging to the Lower Productus Limestone stage. The Eocene has increased in thickness to 450 to 500 feet, mainly limestones, representing the Khairabad Limestone stage, being clearly exposed below the Patala shales especially at the head of the Nilawan ravine.

In the slopes of the Nilawan near its exit, the Purple Sandstones and Neobolus Shales with relatively thin micaceous sandstones above are well-exposed. The upper part of the Magnesian Sandstone series is absent, having been eroded away during pre-Talchir times. Further north along the sides of the gorge, the Magnesian Sandstones die out entirely and the Talchir Boulder-bed, often very thin, rests directly on the Neobolus shales.

Below the Purple Sandstones, the Saline series is exposed in the basal slopes, the Salt Marl stage including thick outcrops of rock-salt at a number of places. The outcrop of the Saline series widens considerably in the upper part of the gorge where the old Nurpur mine is situated.

As above mentioned, fossiliferous Lower Productus beds come in above a well-developed Upper Carboniferous sequence, the arenaceous Productus

Limestones of this basal stage of the series being usually recognisable by the occurrence of *Productus*, *Spirifer*, *Fusulina* and other fossils.

The dark red impure laterite which marks the junction of the Upper Palaeozoic and the Eocene is well-exposed in a number of sections. Above the Patala shales, the Nammal and Sakesar stages (Laki) form limestone cliffs capping the slopes, whilst on the plateau around Nurpur, flaggy limestones of the Bhadrar stage (Laki) cap the Eocene sequence and are succeeded by green sandstones and red clays typical of the Lower Nimadrics. A basal Nimadric conglomerate composed of Eocene limestone pebbles is well-exposed over wide areas of the plateau, closely cemented to the topmost limestones of the Laki stage.

The general structure of the gorge section is an anticlinal with dips at moderate angles to the east and west. At the 'U' bend near the "Salt Pits" about two miles upstream from the gorge exit, Purple Sandstones and higher Palaeozoic beds crop out as a steeply-dipping narrow zone along the crest of the anticline. This outcrop represents the result of local overfolding and faulting along the main anticlinal axis though, in addition, subsidence into the soluble Salt Marl has probably occurred. At the head of the gorge just east of Nurpur, faults running in a west-north-westerly direction intersect the sequence. This zone of faulting apparently continues *via* Sehti to the Vasnal area.

(I) *Vasnal Area.* (Sheet 43 D/10).

(See Plate 7).

Three-quarters of a mile west of Vasnal village, the Punjab Saline series crops out along a faulted dome to form the Vasnal Salt inlier. The inlier is about one mile in a N.-S. direction and $\frac{1}{4}$ mile across. Along the eastern side of the inlier immediately west of Vasnal village, the Salt Marl abuts against the Eocene, but followed further north, thin, *Productus* Limestones and Speckled Sandstone beds come in normal order below the latter. At the northern end of the inlier the Salt Marl Hill is capped by Purple Sandstone rocks which are directly overlain by an outlier of Talchir conglomerates.

Following along the western boundary of the inlier from north to south, Lower Nimadrics are at first faulted directly against the Saline series but, as we go southwards, the fault decreases in intensity and below point 2878 the Eocene limestones with thin *Productus* Limestones below occur on the western side of the fault. Still further south at the southern end of the inlier, Speckled Sandstones and Purple Sandstones crop out above the Saline series.

The evidence of these Palæozoic and Purple Sandstone strata overlying the Saline series of the inlier, at several places, and the absence of Salt Marl among the normal Eocene sequence of the slopes adjoining the inlier, clearly show that the marl and gypsum in question belongs to the same Punjab Saline series as is exposed in the Salt Range scarp.

IV. *Warcha—Chittidil Area.* (Sheets 38 P/14 and 15).

(See Plate 8, Figs. 2 and 3; Plate 9, Fig. 1; Plate 14, and Plate 15, Fig. 1, and Plate 16).

(The Warcha area is best examined from Warcha Mandi at which place is the Government Salt Mine; also a Circuit House. Permission to occupy accommodation can be obtained from the Administrative Officer, Central Excise and Salt, P. O. Khewra. Warcha Mandi is reached from Gunjiyal Railway Station, N.W.R., a distance of eight miles. From Warcha Mandi, camel transport can be arranged to Chittidil where there is a District Rest House, regarding which application should be made to the Deputy Commissioner, Shahpur District, P. O. Sargodha).

The area in question is included in Plate 3 of my contribution to the 1944 Symposium. The geological sequence and structure has largely been described in that contribution and is again referred to above. The area includes excellent sections for studying—

- (a) The whole Salt Range sequence including Cambrian beds (3-5 at Chittidil), and the Upper Palæozoic including both the Talchir Speckled Sandstone Lavender Clay sequence and the Productus Limestone series. In addition the Trias and Eocene are well-represented.
- (b) From the point of view of the age of the Saline Series, the area includes the critical section described in my above mentioned papers.

The following geological tours are suggested:—

- J. The Warcha Mandi Salt Mine.
- K. Hill slopes east of the Circuit House.
- L. Warcha gorge section.
- M. Fatehpur Maira gorge—Salgi Wahan area.
- N. Sections around point 2055, north-east of Chittidil.
- O. Section near Amb.
- P. Sections west and south-west of Ratta.

Tours J, K and L can conveniently be carried out from Warcha Mandi, tour M when moving from Warcha Mandi to Chittidil and the remainder from Chittidil Rest House.

Brief notes on the above are as follows :—

J. *Warcha Mandi Salt Mine.* (Sheet 38 P/15).

(See Plate 8, Fig. 2; Plate 15, Fig. 1 and Plate 16).

The Warcha Salt Mine is located in the western slopes of the gorge just north of Warcha Mandi village. The general sequence within the mine includes :—

(Lavender Clays—Upper Carboniferous)

..... (fault)

Gypsum, dolomite, etc.

Red marl, *kallar* and thin seams of rocksalt alternating.

Rocksalt, varies from 8 to 16 feet.

(Marl, usually only 6 inches to one foot thick).

Rocksalt, varies from 5 to 16 feet.

(Marl, 2 to 6 feet).

Rocksalt, varies up to about 12 feet.

(Marl, 15 to 22 feet).

Rocksalt, the 'Main seam' of the north-eastern part of the mine, up to 50 feet thick.

(Marl, 25 to 30 feet).

Rocksalt, 20 to 30 feet thick in the southwestern workings.

Marl and *kallar* with thin seams of salt (base not seen).

The strata generally dip westwards into the hillside at about 30°, the pillars and chambers being aligned parallel to this westerly dip. To the west, however, the Salt Marl is cut off by faults that bring in the purple and grey Lavender Clays in the northwestern workings. A fault also appears to affect the strata to the south of the present mine.

In addition to affording an excellent example of the banding of the rock-salt, the New Low Level Tunnel section is of interest in illustrating the very recent movement of the Saline beds across unconsolidated sub-Recent gravels, as mentioned above.

K. *Hill-slopes east of Warcha Circuit House.* (Sheet 38 P/15).

(See Plate 8, Fig. 2).

The section in these slopes includes repetitions of the upper part of the Salt Marl stage together with the overlying Upper Gypsum-Dolomite stage, upon which rests the Purple Sandstones series. The latter include maroon shales and flags at the base with massive, jointed maroon sandstones coming in above. The junction between the maroon shales and the topmost gypsum of the Punjab Saline series is undisturbed in a number of sections; in addition, the basal shales contain thin bands of gypsum. In certain of the repetitions the Upper Carboniferous also occurs, the Talchirs directly overlying the Purple Sandstones. In this Upper Carboniferous sequence, the green grey *Conularia* stage (No. 7) underlain by a thin Talchir Boulder bed is easily recognised.

About half a mile south of the Circuit House, steeply dipping *Productus* Limestones occur at the base of the slopes, their present position being the result of faulting.

L. *Warcha Gorge Section.* (Sheet 38 P/15).

(See Plate 15, Fig. 1.)

This section includes the exposures of the lower Gypsum-Dolomite stage (Punjab Saline series) containing oil shales and has been described in several contributions to the Symposium. These beds crop out beneath the Salt Marl stage on either side of the gorge about $\frac{1}{4}$ mile upstream from the Salt Mine, the best sections being those around the junction of the main Warcha gorge and the Jansukh tributary. Sharp folding and faulting has resulted in the repetition of this sequence. The higher strata are best exposed in the western slopes of the main gorge where, a short distance upstream from the Salt Mine, the full sequence is exposed. A very thin Talchir Boulder-bed rests directly on the Purple Sandstones.

Regarding the *Productus* Limestones, excellent sections occur at the water-fall (Mitha Pattan) about $2\frac{1}{2}$ miles up the main gorge and in the section beyond where the limestones are repeated by an overfold accompanied by reversed faulting (*see* paper by F. R. Cowper Reed, G. de P. Cotter, and H. M. Lahiri entitled "The Permo-Carboniferous succession in the Warcha valley, Western Salt Range, Punjab", *Rec. Geol. Surv. Ind.*, LXII, pp. 412-443, 1930).

M. *Fatehpur Maira Gorge—Salgi Wahan Area.* (Sheet 38 P/15).

(See Plate 8, Fig. 3).

Entering Fatehpur Maira gorge (south-eastern branch), the best route to follow is by the path which runs for some distance in the gorge bed and then continues northwards and northwestwards up the slopes across the Saline series to meet the Productus Limestone ridge $\frac{1}{2}$ mile north-west of point 2443. From there, one can drop down across the Productus Limestones dip-slope into the Salgi Wahan, which flows north westwards to join the Dhodha Wahan opposite hill 2055.

At the entrance to the Fatehpur Maira gorge, sections of the upper stages of the Punjab Saline series together with overlying Purple Sandstones are well-exposed. The latter are directly overlain by the Upper Carboniferous, of which the lowest member—the Talchir Boulder bed—is very thin and often difficult to spot. This sequence is repeated by faulting in the lower reaches of the gorge.

Further upstream the Lower Gypsum-Dolomite stage of the Saline series crops out beneath the Salt Marl stage and, as a result of repetitions by fold-faulting, these dolomite-gypsum-oil shale beds occur over a relatively wide area, in general dipping northeastwards at steep angles. As mentioned above the sequence closely resembles that of the Warcha Mandi gorge. Continuing up the Salt Marl slopes in a northwesterly direction, we see evidence of the extrusion of the red saline marl along the crest of the main N.W.-S.E. anticline, the Red Marl having flowed down the slopes on the Speckled Sandstones and Lavender Clay beds, $\frac{1}{2}$ mile south of point 2443. ~

In the Salgi Wahan section the sequence, again dipping northeastwards, is repeated by a reverse fault which brings Productus Limestones (on the north-east) on to thin Siwalik sandstones (to the south-west). The general dip is north-easterly at a steep angle. The above mentioned Siwalik sandstones crop out in the right side of the gorge north of point 2443 and from the lower sandstones black tarry oil seeps at several points.

Continuing down-stream from the oil locality, the gorge cuts across on to older strata, the section including the Eocene sequence followed below by Triassic (Ceratite beds) and Productus Limestones. Of the Eocene, only the lower portion of the Laki limestones and the underlying Ranikot stages are represented.

N. *Section around point 2055 northeast of Chittidil . (Sheet 38 P/15).*

This section, which includes the Punjab Saline series, Purple Sandstone series, and overlying fossiliferous Cambrian beds is described in my paper entitled "Recent Observations on the Cambrian Sequence of the Punjab Salt Range", *Rec. Geol. Surv. Ind.*, *LXVIII*, *part I*, pp. 115-120, 1934, and is also referred to in both contributions to this Symposium. It includes the lowest of the three repetitions of the Chittidil-Sakaser area. The sequence is cut off from the area to the south by a large fault running down the lower part of the Dhodha Wahan. In the Chittidil area the unconformity at the base of the Talchirs is acute, as can be observed by following the boulder-beds across the tract south-west of hill 2055. Whereas, around point 2055, the Talchirs rest on Salt Pseudomorph beds (several hundred feet thick), they are seen to cut across the latter when followed southwestwards towards Chittidil Rest House, and in the sections across the fault near Chhabil the Talchirs rest directly on the Purple Sandstones.

The Cambrian fauna of the area is described by W. B. R. King in *Rec. Geol. Surv. Ind.*, *Vol. LXXV*, *Prof. Paper No. 9*, (1941).

O. *Section near Amb. Sheet 38 P/14).*

(See Plate 8, Fig. 3 and Plate 9, Fig. 1).

The village of Amb is reached by following up the Dhodha Wahan to a short distance beyond its junction with the Salgi Wahan and then continuing up a well-marked path running along the east side of hill 2508. This hill is composed of the Productus Limestones of the lower repetition which in the tributary valley to the south-east of point 2508 are overlain by Triassic and Ranikot beds.

The reversed fault which brings in the Punjab Saline series at the base of the middle repetition is well exposed just south of Amb, where the section is as quoted earlier in this paper. At Amb village, the Purple Sandstones and the overlying Talchirs, etc. (Upper Carboniferous) are well-exposed followed by sharply folded Productus Limestones in Kanjra Range just north of the village. An excellent section of the Productus Limestones is exposed in the path-section running northwards from Amb to Ratta *via* the Dhodha Wahan.

P. *Section west and southwest of Ratta. (Sheet 38 P/15).*

(See Plate 9, Fig. 1; Plate 12, Fig. 2; and Plate 14).

The sequence has been described in my two contributions to the Symposium. To reach sections immediately west of Ratta, it is best to follow

the path *via* Amb village from where it runs northwards across the Dhodha Wahan and continues up the northern slopes into the tributary, half a mile west of Ratta. In and around that tributary, the sections described earlier in this paper occur. To continue westwards and southwestwards along these slopes is difficult and the best way to examine this third repetition further southwest, is by following up the Chittidil-Sakesar pony-tract and then continuing along the Punjab Saline series—Talchir junction to the north-east (towards Ratta) and south-west (towards Golewali).

Younger beds of the sequence—Productus Limestones, Triassic and Eocene—are well exposed in the higher slopes of the Sarai area where they can be studied without difficulty.

V. *Nammal Gorge—Buri Khel Area.*

(See Plate 10).

(The area can conveniently be examined by halting at the District Rest House at Musa Khel, $2\frac{1}{2}$ miles from the entrance to the Nammal gorge. Permission to occupy accommodation is obtainable from the Deputy Commissioner, Mianwali. Musa Khel is 13 miles from Mianwali (N.W. Rly.) and is connected to the latter by a motor road).

Two tours are recommended—up the Nammal gorge within which is exposed an excellent section of the Productus Limestone—Mesozoic-Tertiary sequence of the western part of the Salt Range, and to Buri Khel about 6 miles north of Musa Khel where, in the lower scarp slopes above the village, the Punjab Saline series is directly overlain by thick Talchirs and higher Upper Carboniferous sediments.

Q. *Nammal gorge (Bakh ravine) section.*

A geological map and section of the gorge area are included as Plate 10, Figs. 1 and 2. In the lower part of the gorge, the Middle and Upper Productus Limestones together with the overlying Triassic sequence form a well-marked dome with its axis, somewhat faulted, running N.W.-S.E. Further upstream, younger beds come in successively, dipping northeastwards at 45° to 55° . The sequence is as follows:—

Pleistocene conglomerates. Massive conglomerates including pebbles of Eocene limestone and of older rocks of the Salt Range sequence. Well-exposed in the innermost ridge just behind (southwest of) Nammal village and

to the north across the entrance to the gorge. These beds rest on the Lower Nimadrics (Upper Murrees or Kamlials) with a marked unconformity.

.....(unconformity).....

Lower Nimadrics (Miocene—Pliocene).

Alternating dull green and greenish-grey, massive sandstones and dark red clays and clay-shales. The sandstones include irregular bands of pseudo-conglomerate. At the base is a pebble-bed composed mainly of rounded Eocene limestone pebbles. The thickness of strata exposed totals about 1,500 feet. It is probable that the lower part of the sequence belongs to the Upper Murrees which pass upwards into the Kamlials. The base of the formation is just upstream from the Nammal dam, the junction with the underlying Laki (Sakesar) limestones being locally conformable though, when mapped over a wider region, an unconformity is apparent.

.....(Time-interval; regional unconformity).....

Eocene (1,200 feet).

Sakesar Limestones (*Laki*)

Nammal Limestones and Shales.

Massive and nodular, white and light grey, foraminiferal limestones containing chert concretions, passing down into bedded and marly limestones with light grey and greenish grey calcareous shales; 650 feet.

Patala Shales (Ranikot)—Green and dark grey foraminiferal shales slightly carbonaceous in part, with occasional bands of nodular limestones intercalated. The shales contain selenite, also iron pyrites as small concretions. Foraminifera are numerous. Thickness 235 feet.

Khairabad limestones (Ranikot)—Nodular, white and grey foraminiferal limestones with nodular marls and grey marly clay-shales below; 185 feet.

Dhok Pass beds (Ranikot)—Variable sequence of calcareous, selenite-bearing grey clay-shales, sandy carbonaceous shales and sandstones and thin limestones. Red or grey lateritic bed at the base. Thickness 130 feet.

.....(Time interval; regional unconformity).....

Jurassic (536 to 541 feet).

Baroch limestones—Grey and purplish, fine textured, porcellaneous limestones; thickness 18 feet.

Variegated stage (518 to 523 feet).

- (k) Variegated sandstones and brownish-grey shales alternating; 9 feet.
- (j) Massive yellow-grey and variegated ferruginous sandstones; 38 feet.
- (i) Coal-shales with plant remains alternating with grey sandstones; 4½ feet.
- (h) Alternating massive grey and yellow-brown sandstones grey and brownish carbonaceous shales and sandy shales together with occasional bands of yellow-brown, impure limestone; sandstones predominate; 125 feet.
- (g) Dark red siliceous laterite, splintery; 2½-3 feet.
- (f) Massive yellow and yellow-brown softish sandstones, ochreous in part, alternating with grey and purplish shales and sandy micaceous shales and including several thin, russet-brown, calcareous bands; black carbonaceous shales (4 feet) occur in the lower part; 88 feet.
- (e) Similar lithology to sub-stage (O) but shales predominate over sandstones and, within the lower 25 feet, these shales include dark red, lateritic beds and two thin (one to two feet) bands of carbonaceous shales with coal. Plant fossils occur in the carbonaceous beds. Thickness 170 feet.
- (d) Massive, yellow and grey, pebbly sandstone with small, rounded and semi-rounded quartzite pebbles. With the sandstone, carbonised wood is included as lenticles up to one foot thick. Sulphuretted hydrogen springs issue from near the base of this sub-stage. Thickness 35 to 40 feet.
- (c) Sandy, carbonaceous, grey ochreous shales; 5 feet.
- (b) Variegated, carbonaceous sandstones and shales; 6 feet.
- (a) Hard, grey, weathering brown, fine, calcareous sandstones and fine-textured, bedded limestones with their bands of grey shales; 35 feet.

.....(regional unconformity).....

TRIAS (?) —361-366 feet.

Kingriali Dolomites (186-188 feet.).

- (e) Hard, dark grey, splintery limestone; 14 feet.
- (d) Light grey and yellowish, massive, fine-textured, hard splintery limestones, and dolomitic limestone weathering vesicular near the base. Some fossils visible but difficult to extract; 147 feet.

- (c) Sandy, red, ferruginous band; one foot.
- (b) Yellow-grey, falsebedded, calcareous sandstone; 14 feet.
- (a) Yellow-brown, hard, bedded dolomitic limestone; 11—12 feet.

Kingriali Sandstones (238 to 242 feet).

- (f) Grey and greenish sandy shales; 4 to 5 feet.
- (e) Hard, dark-brown, calcareous sandstone and impure limestone; 1-3 feet.
- (d) Massive grey and yellowish medium-textured sandstone with 3 to 4 feet carbonaceous shale band in the middle; 115 feet.
- (c) Grey and ferruginous, purplish-brown, ripple-marked sandstones alternating with purplish-brown shales and micaceous flags with plant-fragments, the shales predominate in the lower part; 55 feet.
- (b) Hard, fine-textured, greenish-grey weathering russet-brown limestone; 3-4 feet.
- (a) Grey and greenish-grey shales alternating with brownish-weathering limestones and sandstones; 50 feet.
Hard grey and brownish limestone; 10 feet.
.....(conformable, transitional junction).....

TRIAS—(343-345 feet).

Ceratite Beds.

- (f) Grey and purplish, calcareous sandstones, flags and shales alternating, about one half is shale; 64 feet.
- (e) Grey and greenish grey shales with flaggy grey-green sandstone bands; 42 feet.
- (d) Grey and brownish-grey bedded limestone with shale bands, and including numerous badly preserved fossils; 5 feet.
- (c) Grey-green shales with flaggy, grey, *Ceratite*-bearing limestones alternating; limestones prominent in lower half; 51 feet.
- (b) Dull green and flaggy sandstone shales with a few limestone bands, shales predominate; 177 feet.
- (a) Flaggy, grey, *Ceratite* limestone; 4-6 feet.

(Base of Trias, apparently conformable to Upper *Productus* beds, top of the latter is weathered russet-brown).

PERMIAN.

Productus Limestones (703 to 723 feet) and

Upper Productus beds (226 feet).

(c) Brownish-grey, weathering russet-coloured, hard arenaceous limestone; 6 feet.

(b) Soft grey sandy shale; $2\frac{1}{2}$ -3 feet.

(a) Massive, softish, calcareous grey and grey-green sandstone (14 feet) passing down into bedded and semi-nodular, arenaceous limestones and greenish-grey, calcareous sandstones, fossiliferous, with marly bands; a more massive 15-foot band of calcareous sandstone occurs in the middle; shales at the base—217 feet.

(Junction with Middle *Productus* Limestones is quite conformable).

Middle Productus Limestones (477-497 feet).

(d) Semi-nodular and bedded, grey, fossiliferous, hard jointed limestone, 65 feet.

(c) More massive, grey and light-grey, jointed, fossiliferous limestones with crinoids, etc. 312 feet.

(b) Cherty, dark grey, bedded, jointed limestones with their sandy bands; 6-8 feet.

(a) Sandy, grey, limestone at the top, passing down into massive and bedded, jointed grey limestone; black, ? carbonaceous limestone near the base; 100-120 feet.

(Green sandstones and carbonaceous shales of base of Middle *Productus* beds, lower beds not exposed).

The sequence, therefore, includes:—

(Upper Murrees and Kamlials).

Eocene	..	..	1,200 feet.
Jurassic	..	..	536 to 541 feet.
Trias (?)	..	..	361 to 366 „
Trias ..	..	..	343 to 345 „
Permian (Middle and Upper			
Productus Limestones)	..	..	703 to 723+feet.

R. *Buri Khel area.*

The lower and middle scarp slopes southeast of Buri Khel include Productus Limestone, Triassic and Jurassic rocks striking N.W.-S.E. to W.N.W.-E.S.E. and repeated by acute folding and fold-faulting. Dips are usually steep and are often vertical. From beneath this complex sequence, the Speckled Sandstones crop out underlain by the Conularia beds and prominent Talchir conglomerates. In some places, the relatively soft Lavender Clays are cut out as a result of shearing. This Upper Carboniferous sequence crops out over a distance of about a mile in the lower slopes above Buri Khel. The Talchirs are directly underlain by the Punjab Saline series, represented mainly by the Lower Gypsum-Dolomite stage. Similar repetitions by shearing are observed in the case of the Saline series—Talchir succession. This repetition has resulted in a thick outcrop of the gypsum-dolomite-marl beds, thin imbrications of the Talchirs being observed in that sequence whilst at the top, slices of the Saline series with overlying Talchirs are again repeated in the form of relatively thin wedges.

The sections offer a good opportunity of examining the Talchir-Saline series junction which is clearly exposed in the repetitions at a number of places.

V. *Daud Khel area.* (Sheet No. 38 P/9).

(See Plate 2; Plate 9, Fig. 2 and Plate 13, Fig. 2).

(The area can conveniently be examined by halting at the District Rest House, situated close to Daud Khel Railway Station, N.W. Rly. Permission to occupy accommodation can be obtained from the Deputy Commissioner, Mianwali. Alternatively, one can halt at Mari Indus (*see* under VI below) which is linked with Daud Khel by a motorable road—5 miles).

The geology of the area is illustrated in the map forming Plate 2. The area is traversed by the *Jaba nala* just south of which runs the railway-line from Campbellpur.

Two tours are suggested, one to the area south of *Jaba nala* and the other to the north.

(S). *Area south of Jaba nala.*

South of the *Jaba nala*, in the scarp slopes above Khairabad village, Mesozoic beds crop out dipping into the scarp-slopes. In addition to the Trias and Jurassic (including the Baroch Limestones at the top), dark green glauconitic sandstones and shales containing *Belemnites* and *Ammonites*—the Belemnite Beds—occur, followed by massive sandstones—the Lumshiwal

Sandstones of Cretaceous age. The fauna of the Belemnite Beds is described in the Memoir entitled 'The Cephalopoda of the Neocomian Belemnite Beds of the Salt Range' by L. F. Spath see *Pal. Ind., N. S., Vol. XXV, Mem. No. 1*, (1939).

The Lumshiwal Sandstones are overlain by the Eocene sequence, the Khairabad Limestone stage (Ranikot) being very well developed and including mainly light grey, foraminiferal limestones, nodular to semi-nodular, totalling probably 700 feet thick. These form hills 1092, 1184 and also 1948 to the southeast.

Pleistocene alluvial beds (conglomerates and sandstones with some reddish clays) immediately overlie the Khairabad Limestones east of Khairabad, but further south, in the *nala* and ridge about $\frac{1}{2}$ mile north and north-east of pt. 1948 the higher Eocene sequence crops out striking vertically in a N.W.-S.E. direction. Here we see, along the path to Jaba, the development of massive, light-coloured and white gypsum in the top of the Laki. Similar gypsiferous deposits crop out again above Lower Eocene shales with limestones just east of hill 1902, immediately south of the railway-line.

(T). *Area north of the Jaba nala.*

(See Plate 9, Fig. 2, and Plate 13, Fig. 2).

The area north of the Jaba *nala* is of special interest in that it includes outcrops of the Eocene gypsum and also of the Punjab Saline series. The Eocene gypsiferous stage and underlying Ranikot beds (Patala Shales and Khairabad limestones) form the hills one to $1\frac{1}{4}$ miles west-south-west of Ainwan. They are overlain to the east by dark red clays (probably equivalent to the Lower Chharats of the northern Potwar and of the Kohat Salt Region), which are followed above by a thick Nimadric sequence. The latter includes Upper Murees followed by Kamlials, with the Chinji stage cropping out east of Ainwan and the Middle Siwaliks (Nagris) forming ridge 1681 still further east. The dip is northeasterly at $40/50^\circ$ in the case of the lower beds, and decreasing to 20° east of Ainwan village.

The Punjab Saline series, including pink and white gypsum and red marl together with the associated Talchir conglomerates, forms ridge 1127. This area has been referred to earlier in this paper. Intervening between these two gypsiferous occurrences—Eocene gypsum to the east and the Punjab Saline series of ridge 1127 to the west—is a synclinal rift of Siwaliks, largely middle Siwaliks, the beds being vertical in the vicinity of the two faults which cut off

the intervening Siwalik syncline to the east and south-west. The structure is illustrated in the section forming Plate 9, Fig. 2. The Saline series of ridge 1127, together with the overlying Talchirs and Speckled Sandstones form a sharply folded syncline, the south-western limb of which is largely faulted out. As described above the sedimentary contact between the dark-coloured, basal Talchirs and the gypseous marl (Punjab Saline series) is well-exposed, the beds striking vertically in a N.W.-S.E. direction.

At the foot of the hills south of pt. 1127, Eocene (Khairabad) limestones crop out. The limestones are much disturbed and faulted against the Punjab Saline series, which occurs immediately to the north-east.

(VI). *The Mari Indus—Kalabagh Area.* Sheet 38 P/9).

(See Plate 3; Plate 9, Fig. 3; Plate 11, and Plate 12, Fig. 1).

(The area can conveniently be examined from either Kalabagh or Mari Indus, both of which are on the North-Western Railway. At the former are two Rest Houses, one under the jurisdiction of the Administrative Officer, Central Excise and Salt, P. O. Khewra and the other under the Deputy Commissioner, Mianwali. At Mari Indus is the headquarters office of the Makarwal Coal Co., the residential buildings of the Company include a Rest House which can be occupied with the permission of the Company).

The geology of the Kalabagh-Mari Indus area is included in the map forming Plate 3. In this area the strata are greatly disturbed, complicated tectonics being observed in a number of sections. The area is divided into two by the Indus river. Brief notes on the above are as follows:—

(U). *Mari Indus area.*

(See Plate 11, Fig. 2).

The most prominent feature is the Mari Salt hill with exposures of rocksalt, both pink and grey in colour, particularly in the south-western slopes. With the rocksalt and marl irregular, often contorted beds of gypsum and dolomite are intercalated, the former containing bipyramidal quartz crystals—‘Mari diamonds’—which are washed out after heavy rain. The general dip is to the north-east. Both to the south-west and south-east the rocksalt—gypsum-dolomite sequence (the Punjab Saline series) is faulted against Lower Siwalik clays and sandstones, the fault on the southwestern side of the hill being definitely of the reversed type with the Siwaliks dipping beneath the Salt-bearing series.

In the foothills south of the Salt Hill, Khairabad Limestones crop out striking vertically south-eastwards, whilst inside this ridge imbrications of Jurassic strata and of Belemnite beds occur, followed eastwards by a narrow vertical zone of faulted Lower Siwaliks (Chinjis) and then by similarly disturbed Laki (Sakesar) limestones and Kamlials. The latter, dipping steeply to the north-east, pass upwards into relatively undisturbed Chinjis and higher Siwalik beds, clearly exposed near Mari village and in the Indus gorge to the east.

These complicated tectonics are typical of the structures met with in this Mianwali re-entrant. There seems little doubt that the relatively plastic Saline series has been intruded upwards under the influence of the considerable orogenic forces which affected this area in late Tertiary and sub-Recent times and this has added to the complexities of the geological structure as seen to-day. Beneath the Indus river, the Saline series of Mari Salt Hill is no doubt continuous with the similar outcrops seen in the right bank of the river along the southern edge of Kalabagh Hill.

(V). *Kalabagh area.*

(See Plate 9, Fig. 3; Plate 11, Fig. 1 and Plate 12 Fig. 1).

The tectonics of this area are again extremely complicated. The Punjab Saline series crops out in the basal slopes of the southern end of Kalabagh Hill. It includes a considerable proportion of rocksalt, usually as steeply-dipping seams, often contorted and lenticular. The Kalabagh Salt Mine is located in the eastern outcrops of the right bank of the Luni Wahan—the tributary which joins the Indus river opposite Mari village. The lowest stage of the series crops out in the bank of the Indus and also at places a short distance north-west of Kalabagh where it includes gypsum-dolomite beds with associated blue-green, clay-shales and dark, bituminous shales resembling the sequence of the Warcha-Fatehpur Maira area. On the eastern side of the hills in the Luni Wahan section, 7 furlongs north of the Indus, the Salt Marl stage appears to be duplicated by faulting; above the lower repetition, the salt-bearing marl, is overlain by massive gypsum and dolomite resembling the strata of the Upper Gypsum-Dolomite stage.

Resting on the Saline series with a marked discordance is a complex association of younger sediments ranging in age from Upper Carboniferous (Speckled Sandstone stage) to the Pleistocene massive conglomerates (Kalabagh conglomerates) of the summit and eastern slopes of Kalabagh Hill. A marked unconformity occurs at the base of the Kalabagh Conglomerates. The older beds, including Productus Limestones, Trias, Jurassic, Cretaceous, Eocene

and Lower Siwaliks crop out in the western slopes north of Kalabagh where they have been acutely folded and faulted.

In the eastern slopes, at first sight it appears that the Kalabagh Conglomerates, with Upper and Middle Siwalik brown clays and sandstones below, rest directly on the Saline series. Examined more closely, it is seen that this is not the case in many sections. In the tributary sections just south of the Salt Mine, a narrow, sheared zone of marly Eocene limestones with gypsum together with Speckled Sandstones intervenes between the Siwaliks and the salt-bearing series, whilst further upstream a short distance north of the mine, crushed Eocene limestones with green Belemnite beds irregularly associated crop out above the rocksalt.

In so far as the age of the Punjab Saline series is concerned the area offers no indisputable evidence. The rocksalt, etc., has undoubtedly been intruded upwards in late Siwalik times and in so doing remnants of the overlying younger beds (Upper Carboniferous to Pliocene) were carried up to form a much disturbed cap-rock. On this irregularly disposed sequence, the Pleistocene beds (Kalabagh Conglomerates) were laid down.

The complex nature of the tectonics is also clearly observed in the outcrops of the bed of the Luni Wahan just beyond the Salt Mine. The main structure of the Luni Wahan is a fault downthrowing to the east, which brings in the thick Middle Siwalik sandstones and conglomerates in the rugged hills to the east. Along this fault zone just north of the Salt Mine, a small lenticular-shaped 'horst' of steeply-dipping, slickensided Productus Limestones crops out among vertical Siwalik beds in the western portion of the gorge $\frac{3}{4}$ mile north of the Indus River (*see* Plate 12, Fig. 1). The same fault zone continues north-north-westwards up the Luni Wahan intersecting the Siwalik beds and along this valley, about 8 miles north of the Indus, two small plugs of Salt Marl crop out.

As in the case of the Mari Indus Salt Hill, the Saline series has also been sheared southwestwards across Siwalik beds, outcrops of high Siwalik sandstones and conglomerates being observed in the right bank of the Indus at Kalabagh and in the basal slopes to the north-west of the village.

Clear evidence of overthrusting on a considerable scale can also be observed in the sequence above Kuch, 3 to 4 miles north of Kalabagh where Productus Limestones and younger sedimentaries are thrust across steeply-dipping Siwaliks.

GENERAL REMARKS.

To cover all the above-suggested tours would occupy a period of about 35 days distributed approximately as follows:—

I.	Khewra-Dandot-Choa Saidan Shah area	..	7 days.
II.	Jalalpur area .. .. .	..	2 „
III.	Nurpur-Vasnal area .. .. .	..	4 „
IV.	Warcha-Chittidil area .. .. .	..	8 „
V.	Nammal gorge—Buri Khel area .. .. .	..	3 „
VI.	Daud Khel area .. .. .	..	2 „
VII.	Kalabagh-Mari Indus area .. .. .	..	3 „
	Travelling between the various areas, etc. .. .. .	..	6 „
			<hr/> 35 days. <hr/>

For those who are unable to spare the time necessary to examine all the areas, I would suggest the following:—

I.	Khewra-Dandot-Choa-Saidan Shah area	..	4 days.
II.	Scarp slopes west of Jalalpur (by car from Khewra)	..	1 „
IV.	Warcha-Chittidil area .. .. .	..	6 „
VI+VII.	Kalabagh-Daud Khel area .. .. .	..	2 „
	Travelling between the various areas .. .. .	..	2 „
			<hr/> 15 days. <hr/>

If only one week is available, it is recommended that the time be spent at Warcha and Chittidil where the greater part of the Salt Range sequence is represented and the tectonics are of great interest. In addition that area includes probably the most critical evidence of the (Cambrian or pre-Cambrian) age of the Punjab Saline series.

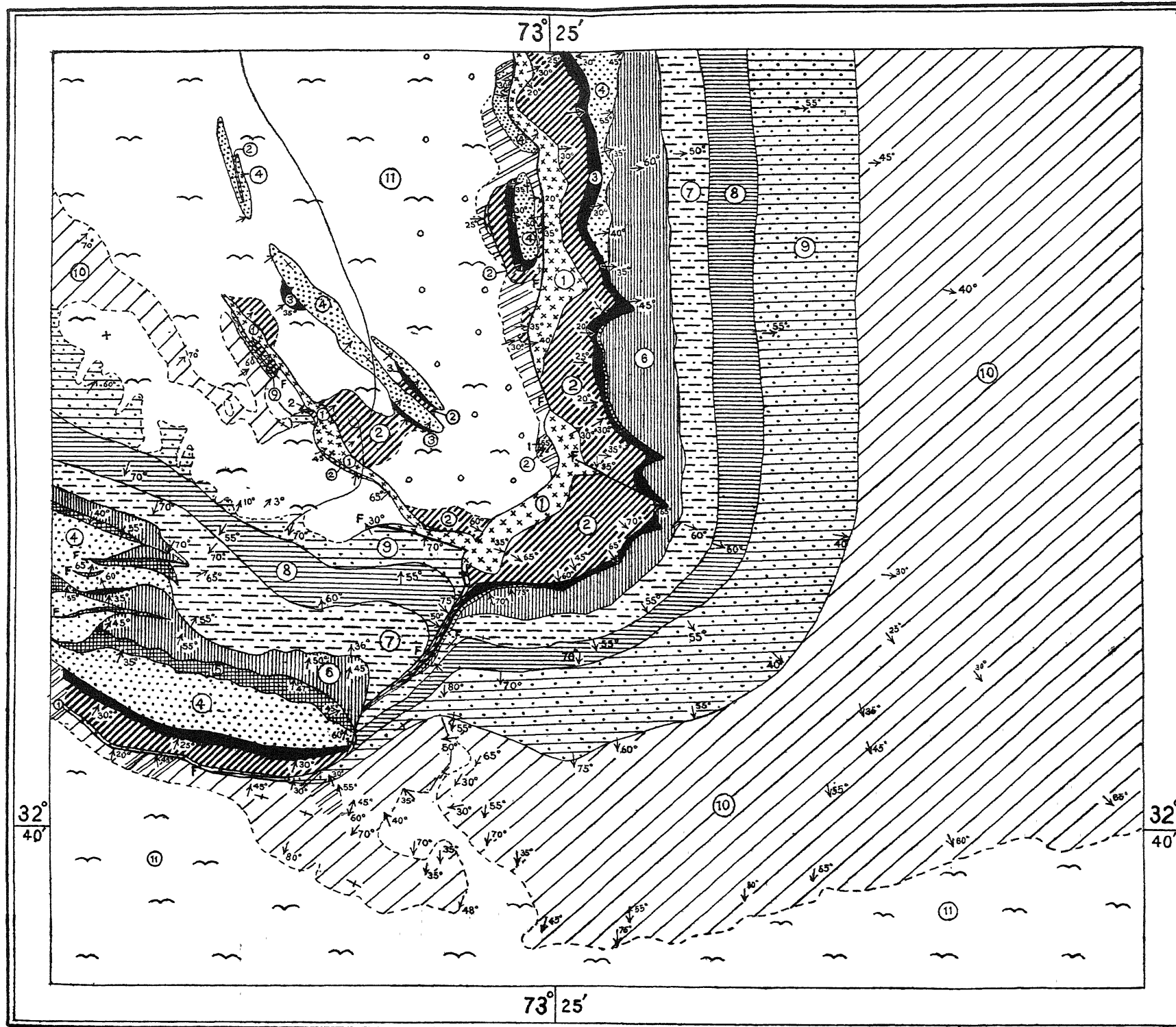
EXPLANATION OF PLATES 1—19.

- Plate 1. Geological map of the Jalalpur area, Salt Range, (2 inches=1 mile).
- „ 2. Geological map of the Daud Khel area, Salt Range, (2 inches=1 mile).
- „ 3. Geological map of the Kalabagh-Mari Indus area, Salt Range, (2 inches=1 mile).
- „ 4. Fig. 1—Section across southern end of Chambal ridge.
Fig. 2—Section across Mangal Dev ridge, Jalalpur area.
Fig. 3—Section through Salt Mine Hill, Khewra and across Khewra gorge.
- Plate 5. Fig. 1—Geological Plan of the Mayo Salt Mines, Khewra, reduced to the level of the Low Level workings.
Fig. 2—Section through the middle part of the Mayo Salt Mine, Khewra.

- Plate 6. Fig. 1—Section across Dandot-Gandhala area.
 Fig. 2—Section through Karangal Hill.
 Fig. 3—Section N.—S. through Dhok Tahlian.
- " 7 Fig. 1—Geological map of Vasnal Salt Inlier.
 Figs. 2 & 3—Sections across the Vasnal Salt Inlier (Stages numbered as in Fig. 1).
- " 8 Fig. 1—Section N.E.—S.W. across the Nilawan at the U-bend 2 miles from the exit.
 Fig. 2—Section across the Warcha gorge, through the Warcha Salt Mine.
 Fig. 3—Section drawn N.—11° W. across the Salgi Wahan and Amb.
- " 9 Fig. 1—Section drawn N.—S. through Amb and Sakesar.
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- " 10 Fig. 1—Geological map of the Nammal gorge.
 Fig. 2—Section across Salt Range at Nammal.
- " 11 Fig. 1—Kalabagh hill viewed from across the Indus river.
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- " 13 Fig. 1—Contorted rocksalt of the western slopes of Kalabagh hill.
 Fig. 2—Gypsum boulder in basal Talchirs near hill 1127, Daud Khel.
- " 14 Fig. 1—Talchirs overlying dolomite (Punjab Saline series), 5 furlongs west of Ratta.
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 Fig. 2—The Salt Range scarp below Dandot.
- " 16 Fig. 1—Banded rocksalt and marl overlying sub-Recent debris in New Low Level Tunnel
 Warcha Salt Mine.
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- " 17 Fig. 1—The Khewra gorge.
 Fig. 2—Sub-Recent beds in the Billianwala gorge, Khewra.
- " 18 Fig. 1—The scarp near Jalalpur.
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- " 19 Fig. 1—Punjab Saline series thrust over Siwaliks at Chitti, near Jalalpur.
 Fig. 2—Fault zone of gypseous marl and Cambrian among Nimadrics near Jalalpur.

GEOLOGICAL MAP OF THE JALALPUR AREA, SALT RANGE

Plate I.



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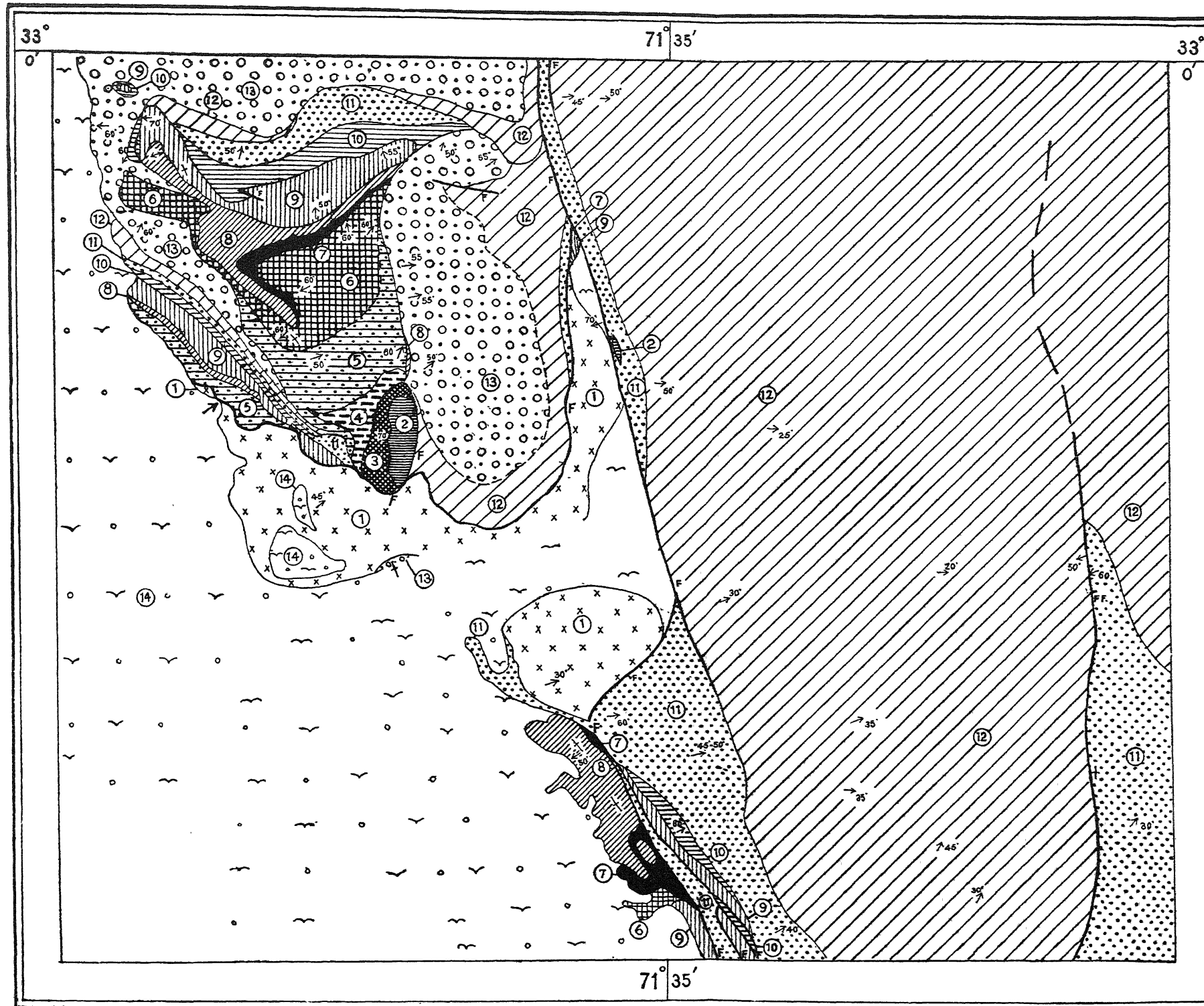
- | | | |
|----|--|--|
| 11 | | Alluvium (Recent). Boulder detritus. o o o |
| 10 | | Upper Siwaliks. |
| 9 | | Middle Siwaliks. |
| 8 | | Chinji stage. |
| 7 | | Kamlial stage. |
| 6 | | Murrees. |
| 5 | | Salt Pseudomorph Beds. |
| 4 | | Magnesian Sandstones. |
| 3 | | Neobolus Shales. |
| 2 | | Purple Sandstones. |
| 1 | | Punjab Saline series. |
| | | Extensive scree deposits (mainly of Purple Sandstones and Magnesian Sandstones.) |
| | | Fault. |
| | | Dip. |
| | | Vertical beds. |
| | | Horizontal beds. |

Scale 0 1/2 1 mile

By E. R. GEE.

GEOLOGICAL MAP OF THE KALABAGH-MARI INDUS AREA, SALT RANGE

Plate 3.



INDEX

- | | | |
|----|--|---|
| 14 | | Recent & Sub-Recent Alluvium. |
| 13 | | Kalabagh Conglomerates (Pleistocene). |
| 12 | | Middle Siwaliks (including ? Upper Siwalik clays of Kalabagh Hill). |
| 11 | | Chinji stage (Lower Siwaliks). |
| 10 | | { Kamlial stage (" ")
Murrees. |
| 9 | | Laki. (Limestones & Shales) |
| 8 | | Ranikot. (" ") |
| 7 | | { Lumshiwal Sandstones } L. Cretaceous-
Belemnite Shales } Up. Jurassic. |
| 6 | | { Baroch Limestones } Jurassic.
Variegated stage } |
| 5 | | { Kingriali Dolomites } Trias.
" Sandstones } |
| 4 | | Ceratite Beds. (Trias) |
| 3 | | Upper Productus Beds. (Permian) |
| 2 | | Middle Productus Limestones. (Permian) |
| 1 | | Punjab Saline series. (Cambrian or Pre-Cambrian) |
| | | Fault. |
| | | Dip. |
| | | Vertical beds. |
| | | Horizontal beds. |

Scale 0 1/2 1 mile

By E. R. GEE,

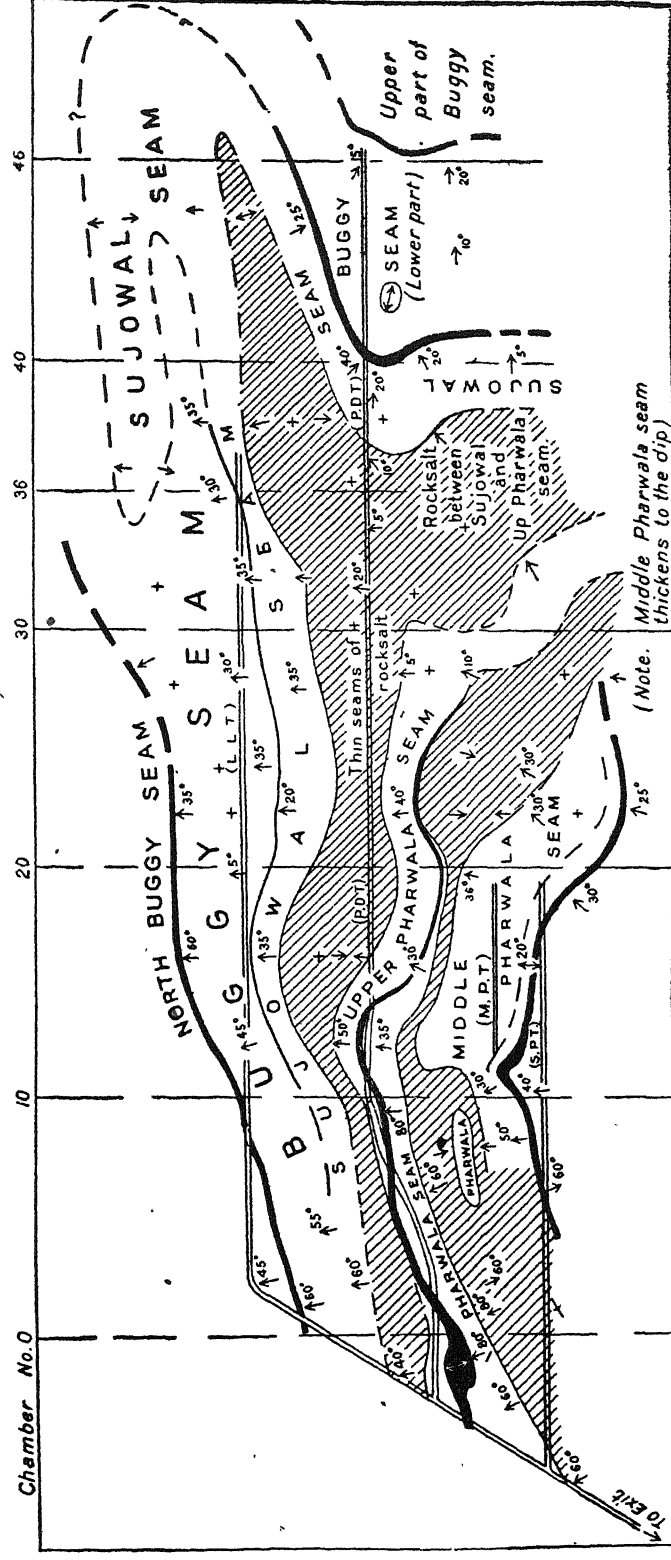


Fig. 1.—GEOLOGICAL SECTION OF THE MAYO SALT MINES, KHEWRA, REDUCED TO THE LEVEL OF THE LOW LEVEL WORKINGS.

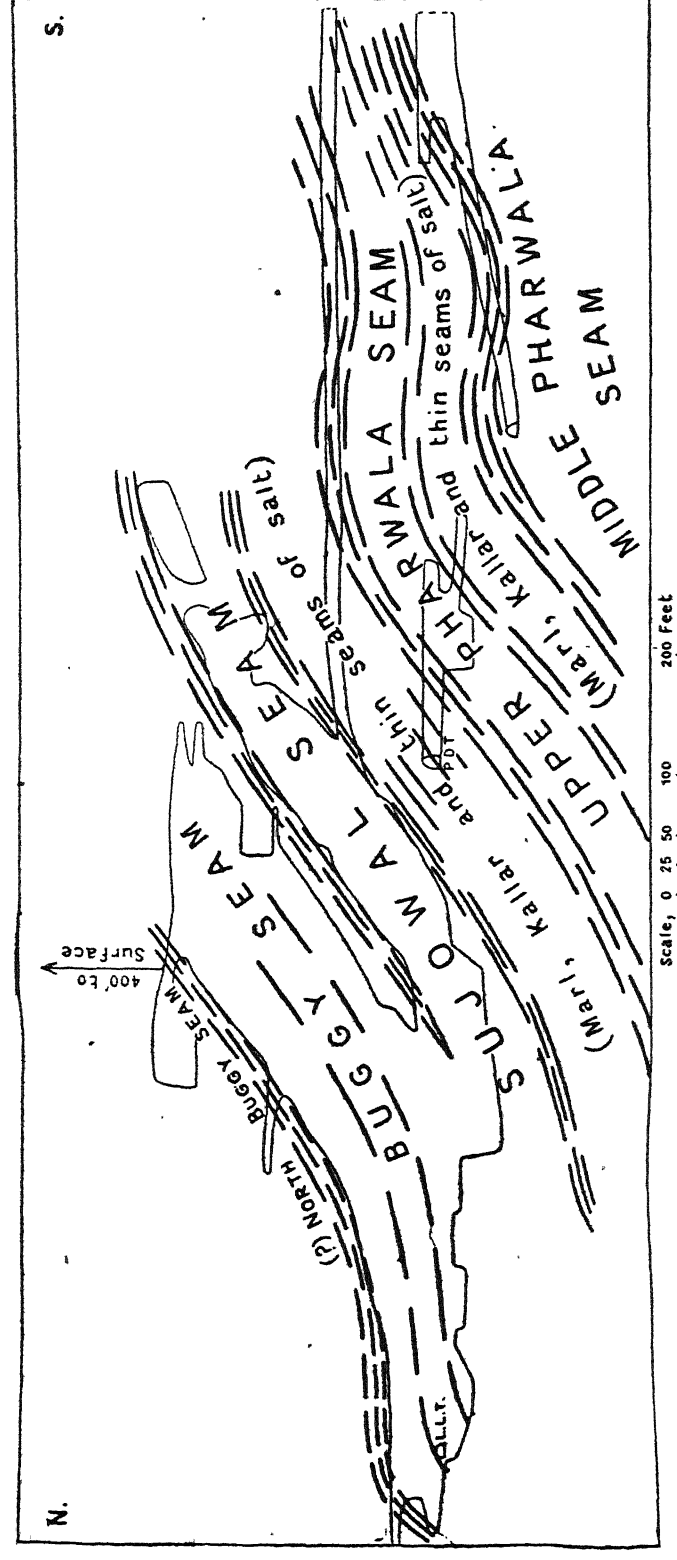


Fig. 2.—SECTION THROUGH THE MIDDLE PART OF THE MAYO SALT MINE, KHEWRA.

Plate 6.

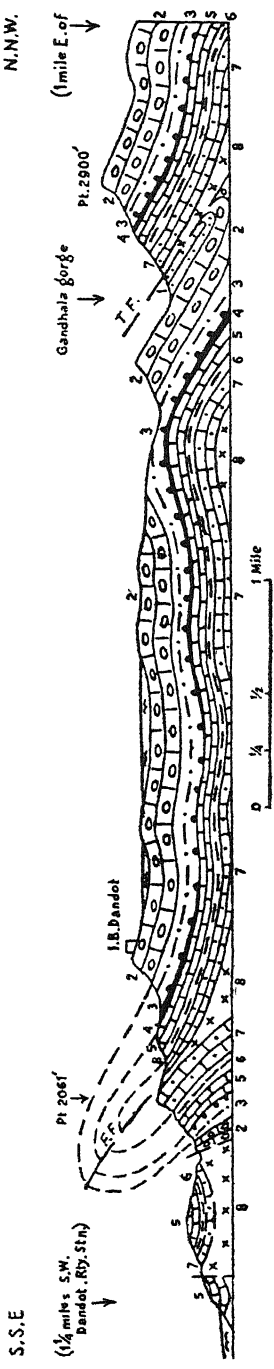


Fig. 1 SECTION DRAWN N. N. W. ACROSS THE DANDOT SCARP AND PLATEAU, AND CONTINUED ACROSS THE GANDHALA GORGE TO ONE MILE EAST OF WAULA ($32^{\circ} 43' : 72^{\circ} 54'$).

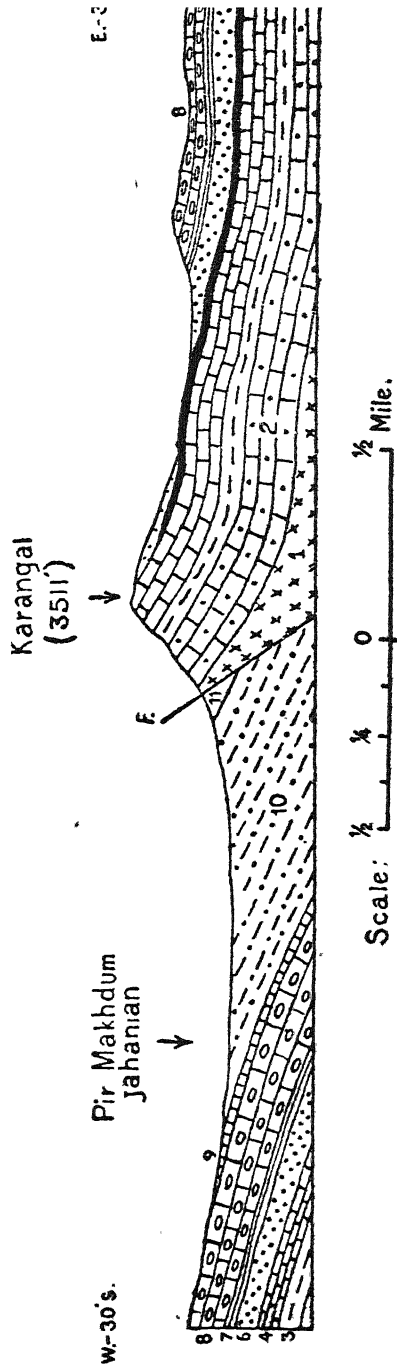


Fig. 2. SECTION THROUGH KARANGAL HILL.

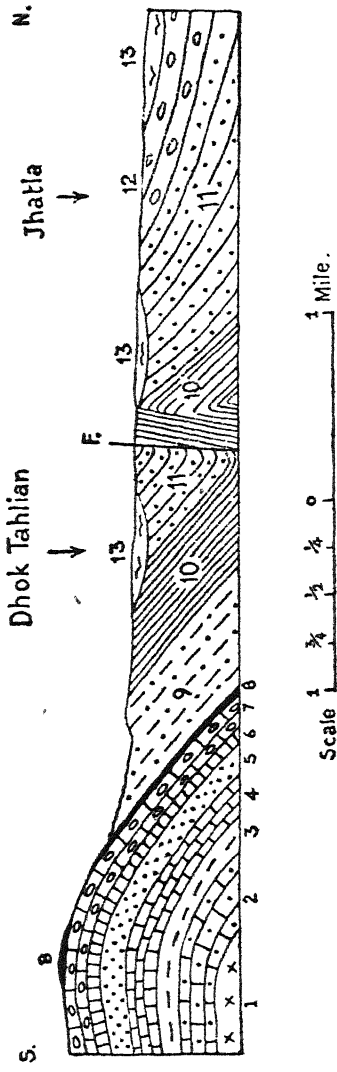
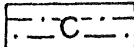

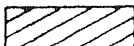

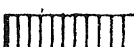
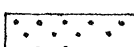

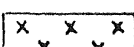
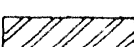
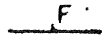



Fig. 3. SECTION N. - S. THROUGH DHOK TAHLIAN.

INDEX

- | | | |
|---|---|---------------------------------|
| 8 |  | Chinji stage |
| 7 |  | Kumliat - Murree |
| 6 |  | Laki |
| 5 |  | Ranikot |
| 4 |  | Productus Limestones |
| 3 |  | Speckled Sandstones
Talchirs |
| 2 |  | Purple Sandstones |
| 1 |  | Punjab Saline series |
| |  | Scree |
| |  | Fault |
| |  | Vertical strata |

Scale $\frac{1}{2}$ $\frac{3}{8}$ $\frac{1}{4}$ $\frac{1}{8}$ 0 $\frac{1}{2}$ Mile.

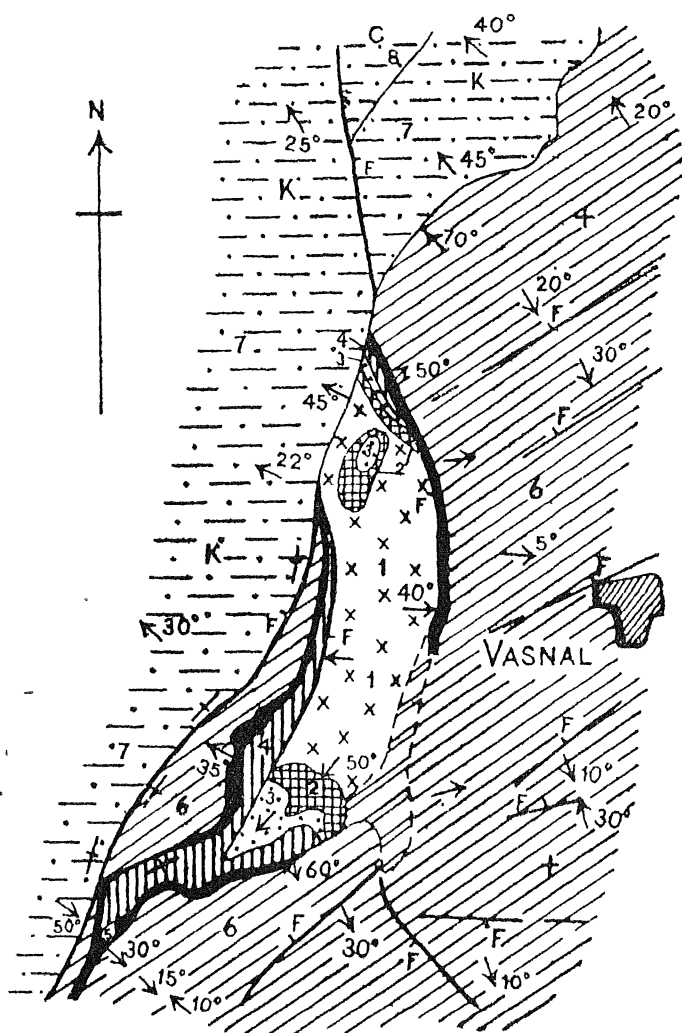


Fig. 1. GEOLOGICAL MAP OF VASNAL SALT INLIER

← ----- $2\frac{1}{2}$ Miles (approx.) ----- →
S. 15°- W. N. 15°- E.

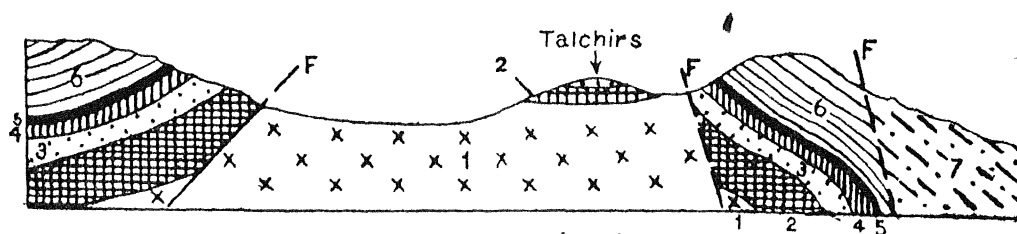


Fig. 2.

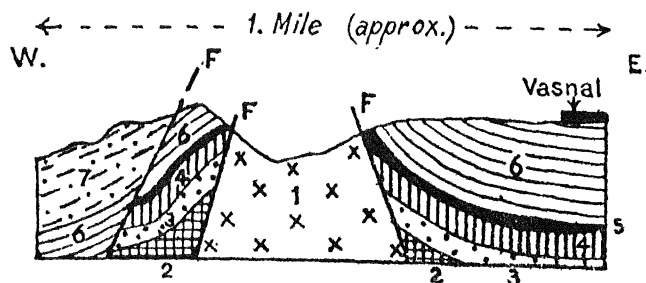
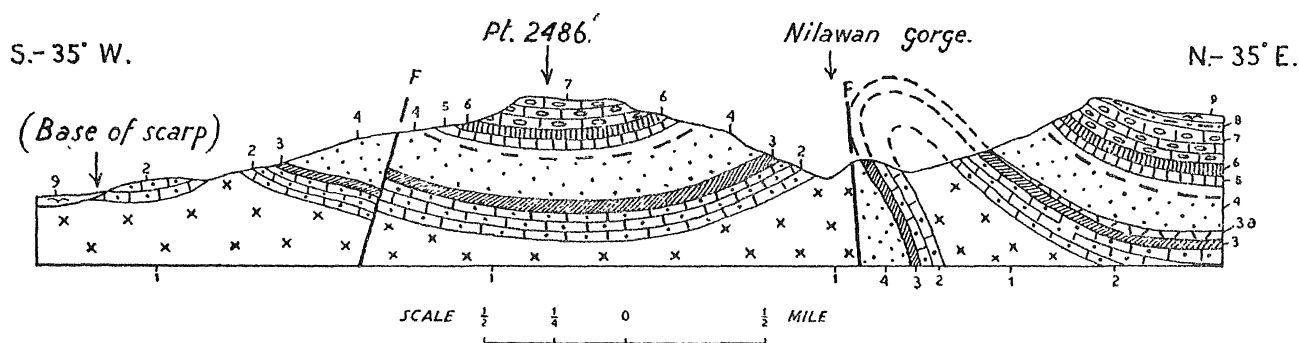


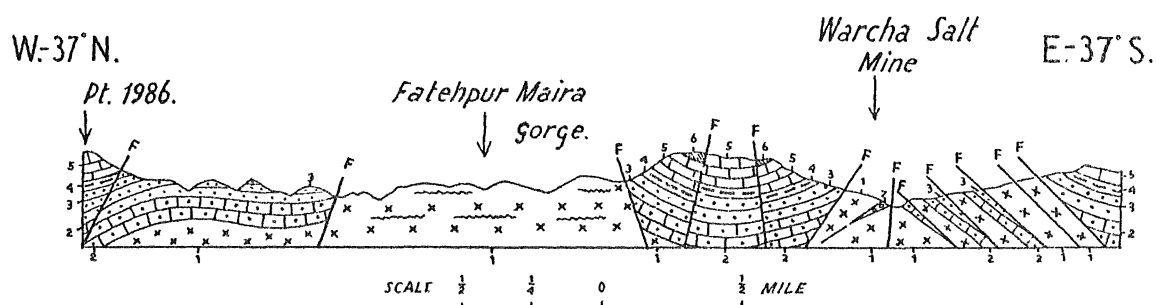
Fig. 3.

Figs. 2 & 3. SECTIONS ACROSS THE VASNAL SALT INLIER.
(Stages numbered as in Fig. 1.)



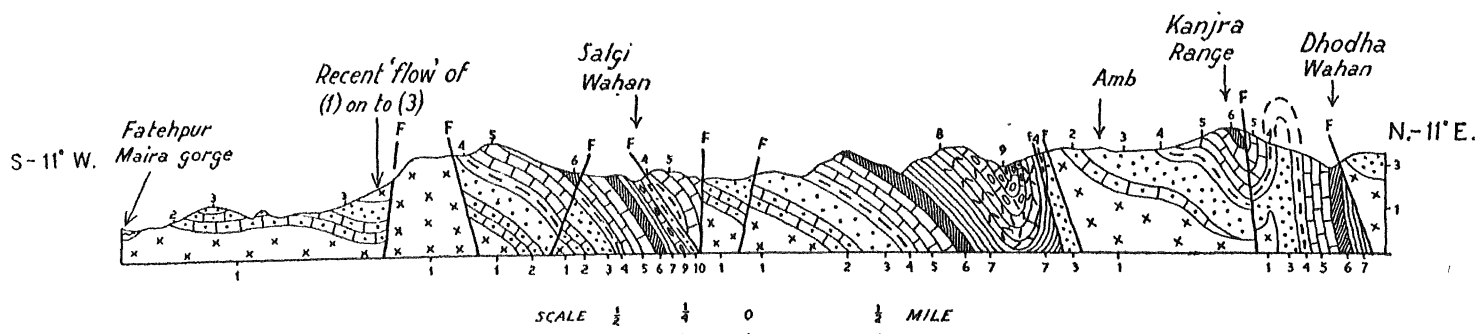
9. Alluvium. 8. Kamlials. 7. Laki. 6. Ranikot. 5. Lower Productus Beds. 4. Upper Carboniferous (Talchir Boulder-bed at base). 3(a). Magnesian Sandstones. 3. Neobolus Shales. 2. Purple Sandstones. 1. Punjab Saline series. F. Fault.

Fig. 1. SECTION N.E. - S.W. ACROSS NILAWAN AT U-BEND 2 MILES FROM EXIT.



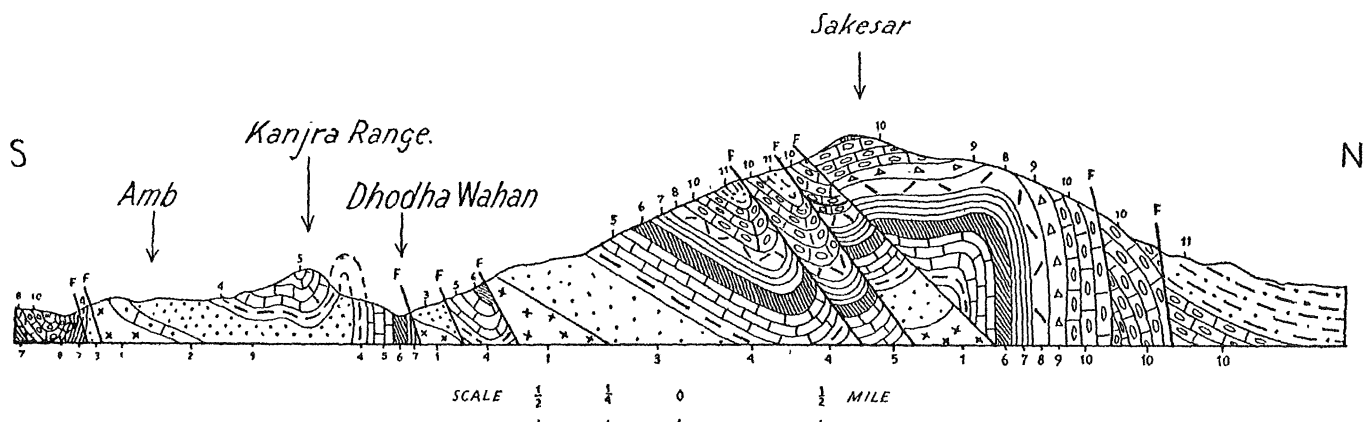
7. Sub-Recent Alluvium. 6. Upper Productus Beds. 5. Middle Productus Limestones. 4. Lower Productus Beds. 3. Upper Carboniferous (with Talchir Boulder-bed at base). 2. Purple Sandstones. 1. Punjab Saline series. F. Fault.

Fig. 2. SECTION DRAWN E. 37° S - W. 37° N. THROUGH WARCHA SALT MINE.



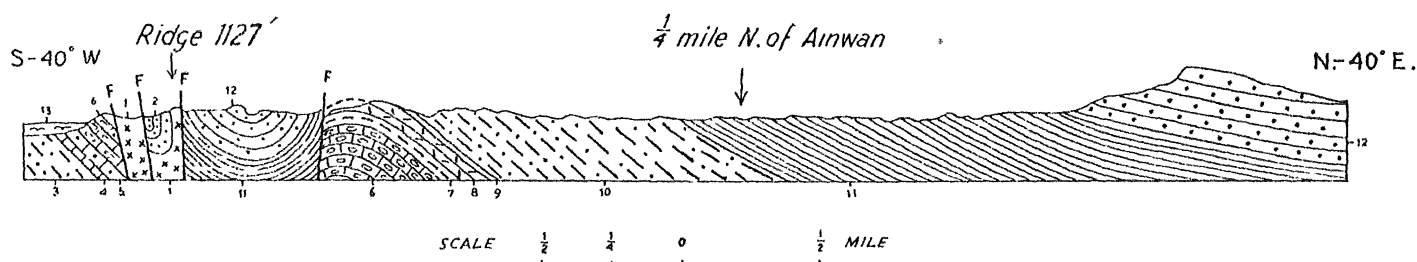
10. Kamlials. 9. Eocene. 8. Kingriali Beds. 7. Ceratite Beds. 6. Upper Productus Beds. 5. Middle Productus Limestones. 4. Lower Productus Beds. 3. Upper Carboniferous (with Talchir Boulder-bed at base) 2. Purple Sandstone series. 1. Punjab Saline series. F. Fault (usually reversed).

Fig. 3. SECTION DRAWN N.-11° E. - S.-11° W. ACROSS THE SALGI WAHAN AND AMB.



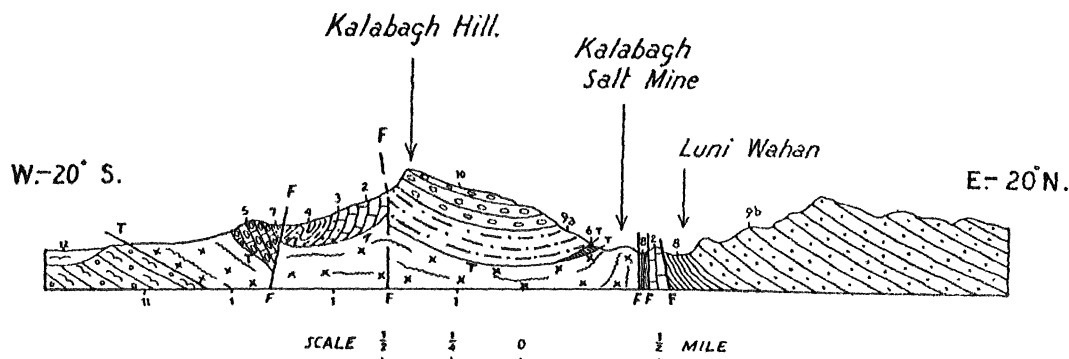
11. Kamlials. 10. Eocene. 9. Variegated Stage. 8. Kingriali Beds. 7. Ceratite Beds.
 6. Upper Productus Beds. 5. Middle Productus Limestones. 4. Lower Productus Beds.
 3. Upper Carboniferous (with Talchir Boulder-bed at base). 2. Purple Sandstones.
 1. Punjab Saline series. F. Fault (usually reversed).

Fig. 1. SECTION DRAWN N. - S. THROUGH AMB AND SAKESAR.



13. Alluvium. 12. Nagri Stage (Middle Siwaliks) 11. Chinji Stage (Lower Siwaliks).
 10. Kamlial Stage (Lower Siwaliks) & Murrees. 9. Lower Chharats. 8. Laki (gypsum facies).
 7. Shales & Limestones (Laki-Ranikot). 6. Khairabad Limestones & Dhak Pass beds (Ranikot).
 5. Lumshiwal Sandstone & Belemnite Beds (L. Cretaceous Up. Jurassic). 4. Baroch Limestones (Jurassic).
 3. Variegated Stage (Jurassic). 2. Speckled Sandstones with Talchirs at base (Up. Carboniferous).
 1. Punjab Saline series (Cambrian or pre-Cambrian). F. Fault.

Fig. 2. SECTION N.E. - S.W. ACROSS THE DAUD KHEL AREA, NORTH OF THE JABA NALA.



12. Recent Alluvium. 11. Sub-Recent Alluvium. 10. Kalabagh Conglomerates.
 9a. Middle Siwaliks and possibly Upper Siwaliks (argillaceous facies). 9b. Middle Siwaliks and possibly Upper Siwaliks (arenaceous facies). 8. Chinjis. 7. Kamlials. 6. Lower Chharats (imbrication).
 5. Laki Limestones. 4. Ceratite Beds. 3. Upper Productus Beds. 2. Middle Productus Limestones.
 1. Punjab Saline series. F. Fault. T. Thrust Junction.

Fig. 3. SECTION THROUGH KALABAGH HILL JUST SOUTH OF SUMMIT.

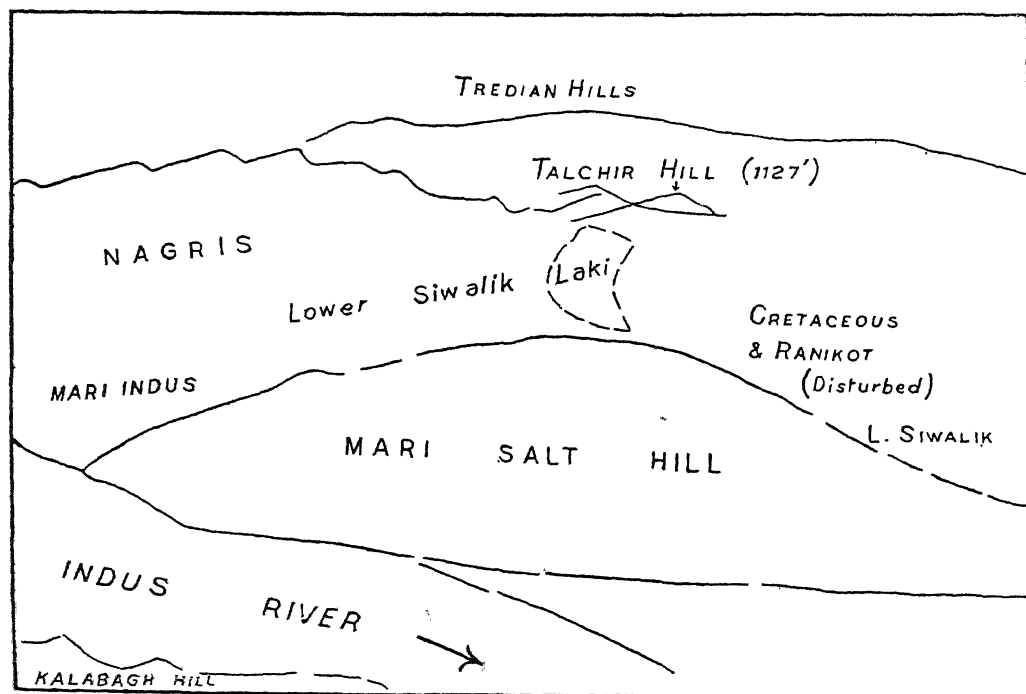
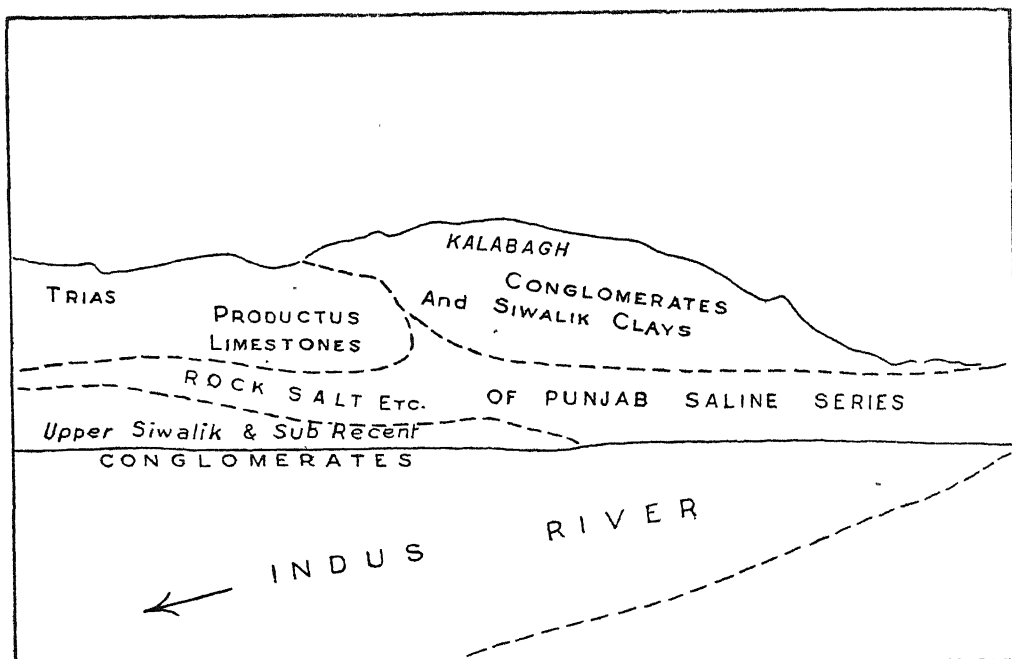




FIG. 1.—KALABAGH HILL VIEWED FROM ACROSS THE INDUS RIVER.



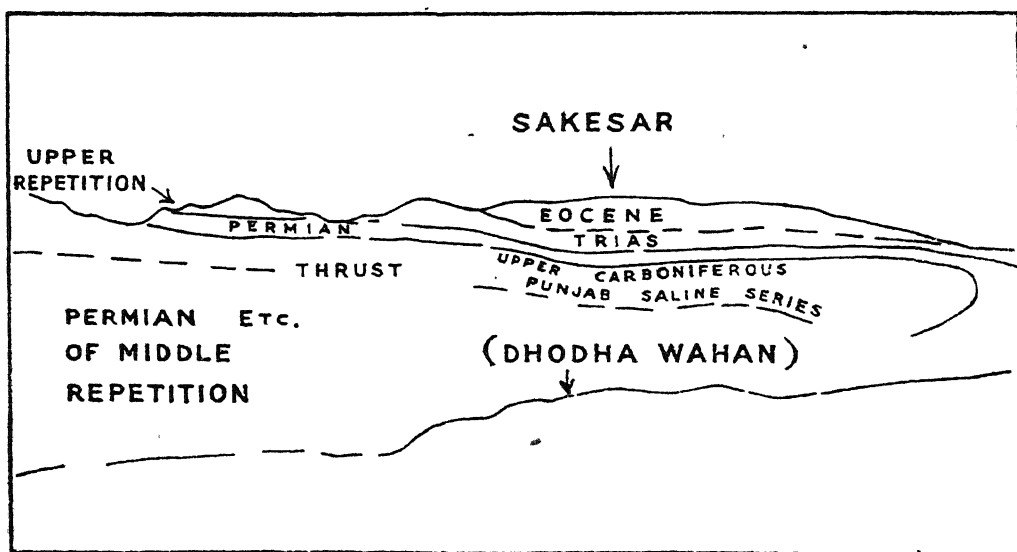
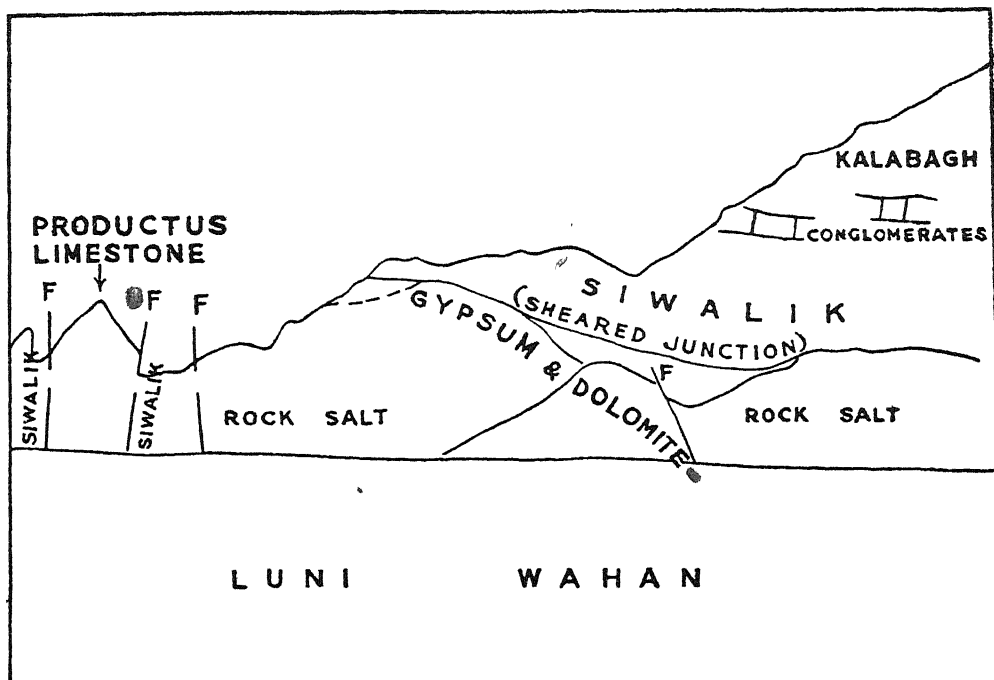
FIG. 2.—MARI INDUS SALT HILL.

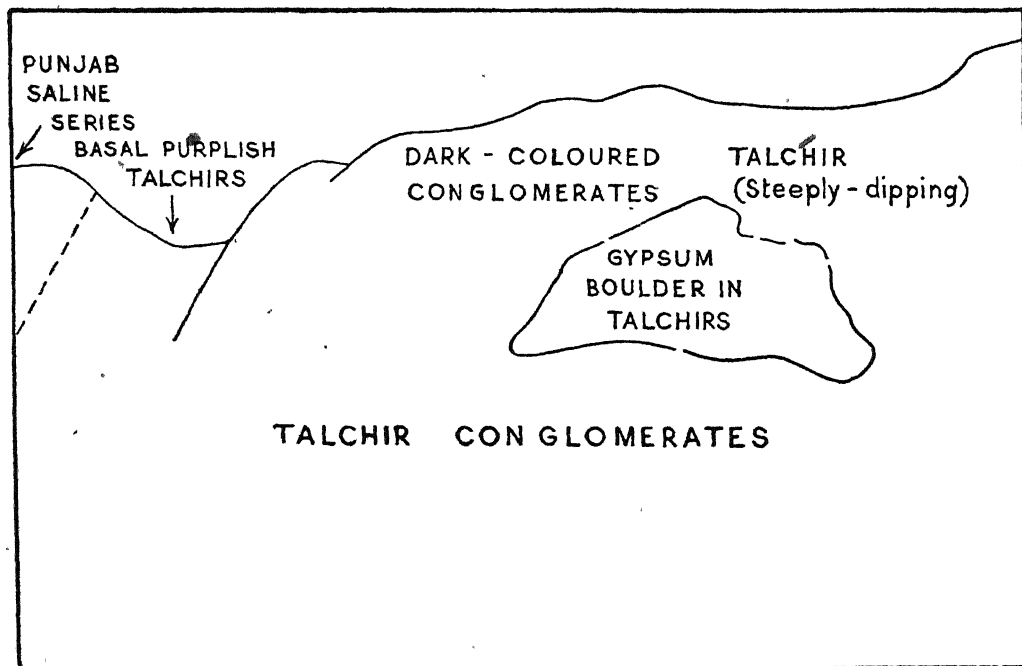
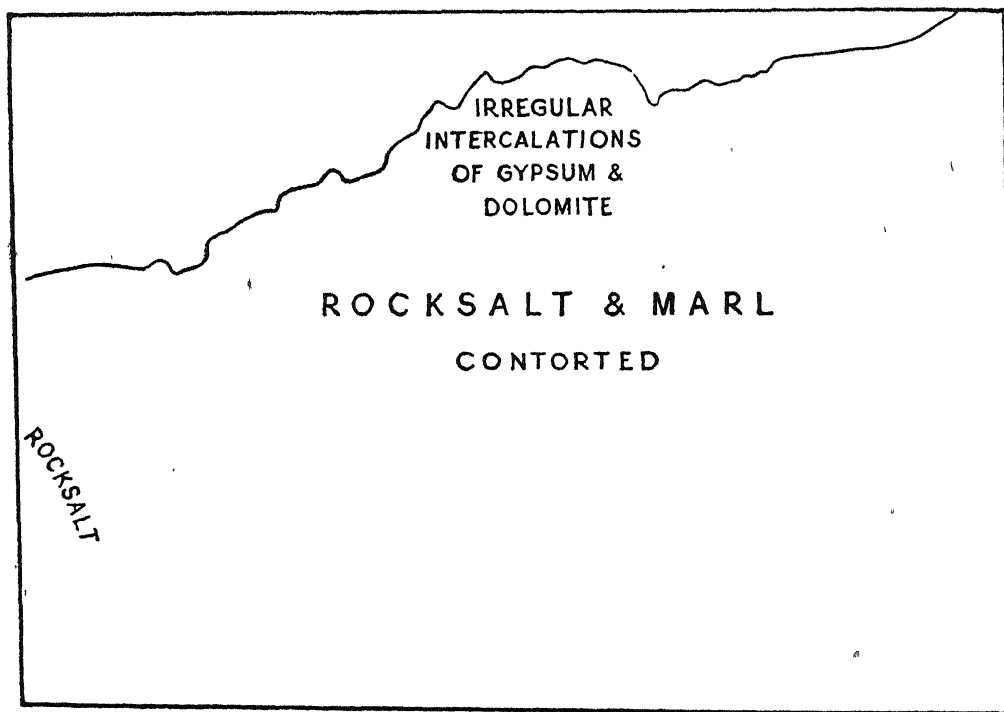


FIG. 1.—LUNI WAHAN SECTION NEAR KALABAGH SALT MINE.



FIG. 2.—NORTHERN SLOPES OF THE DHODHA WAHAN, INCLUDING SAKESAR.





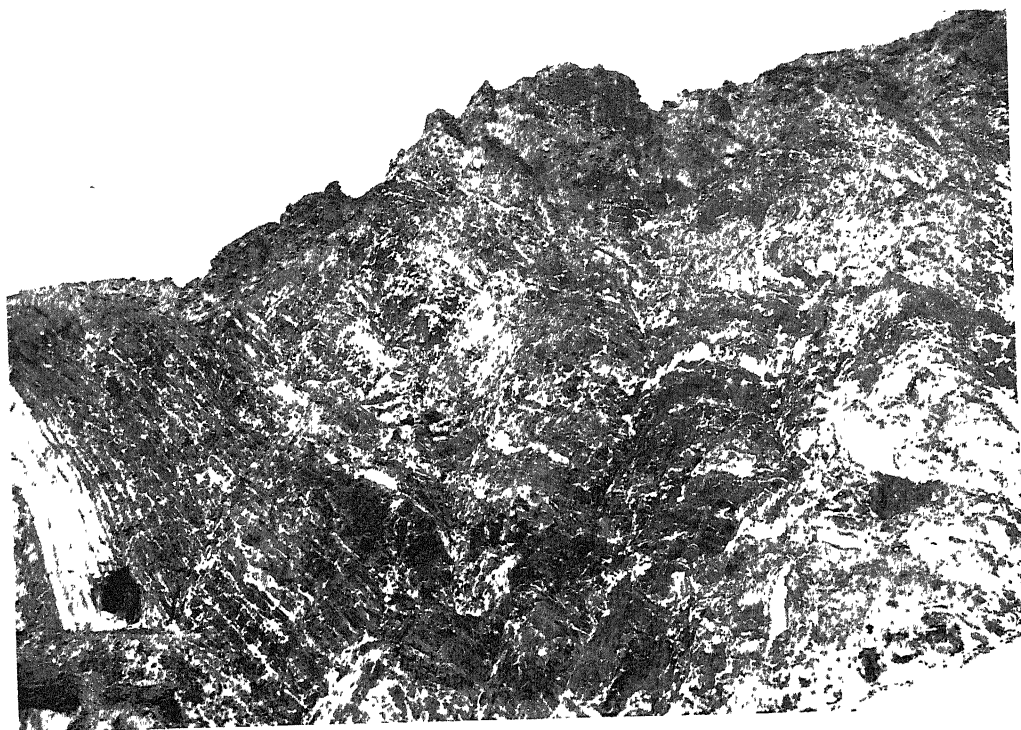


FIG. 1.—CONTORTED ROCKSALT, WESTERN SLOPES OF KALABAGH HILL.



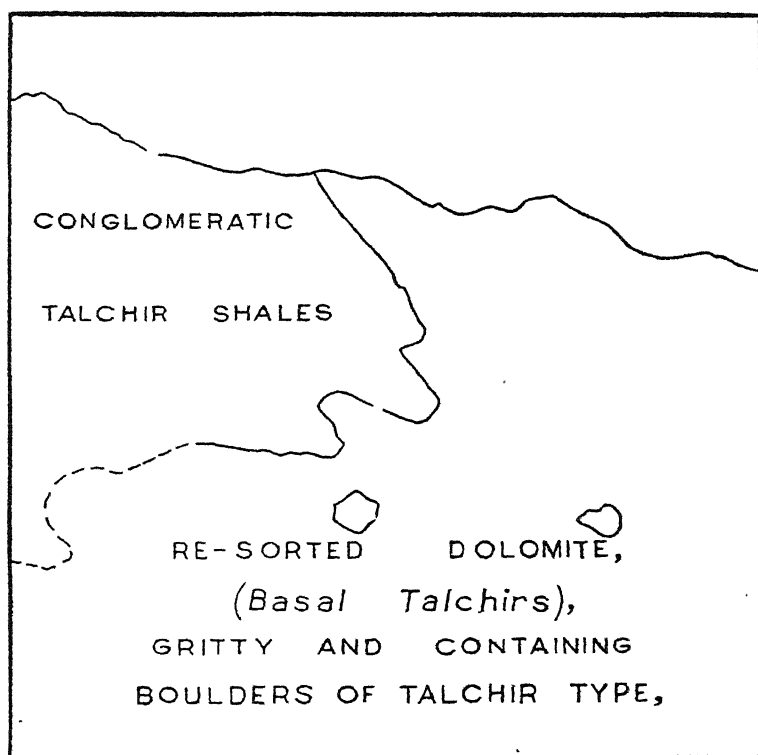
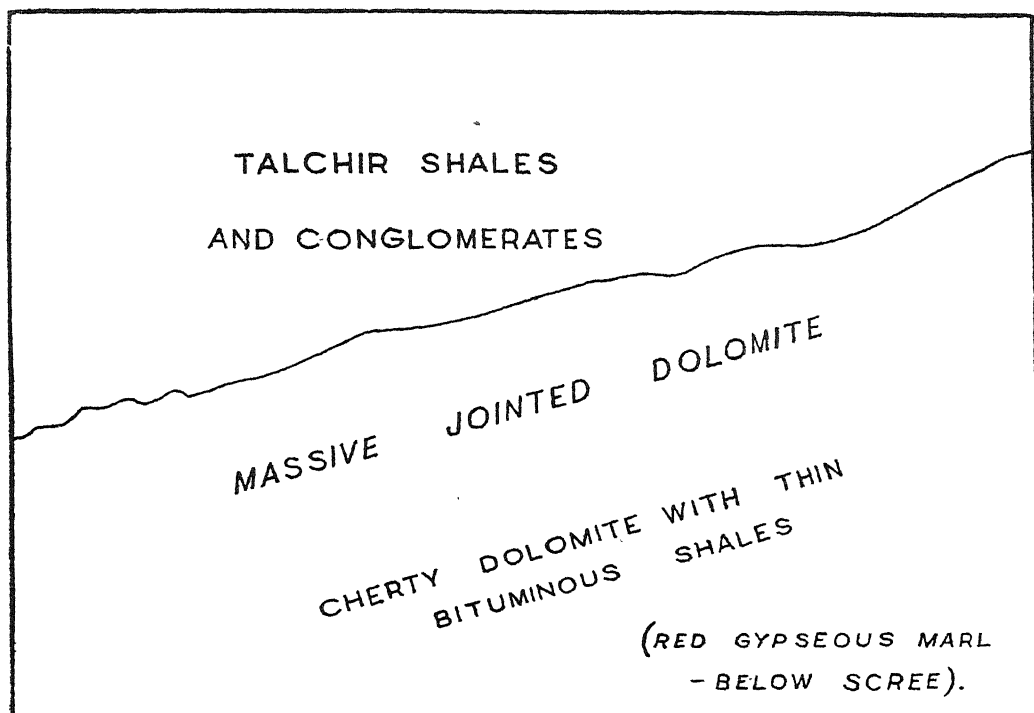
FIG. 2.—GYPSUM BOULDER IN TALCHIRS NEAR HILL 1127.



FIG. 1.—TALCHIRS OVERLYING DOLOMITE (PUNJAB SALINE SERIES) NEAR RATTÀ.



FIG. 2.—DITTO, SHOWING THE JUNCTION.



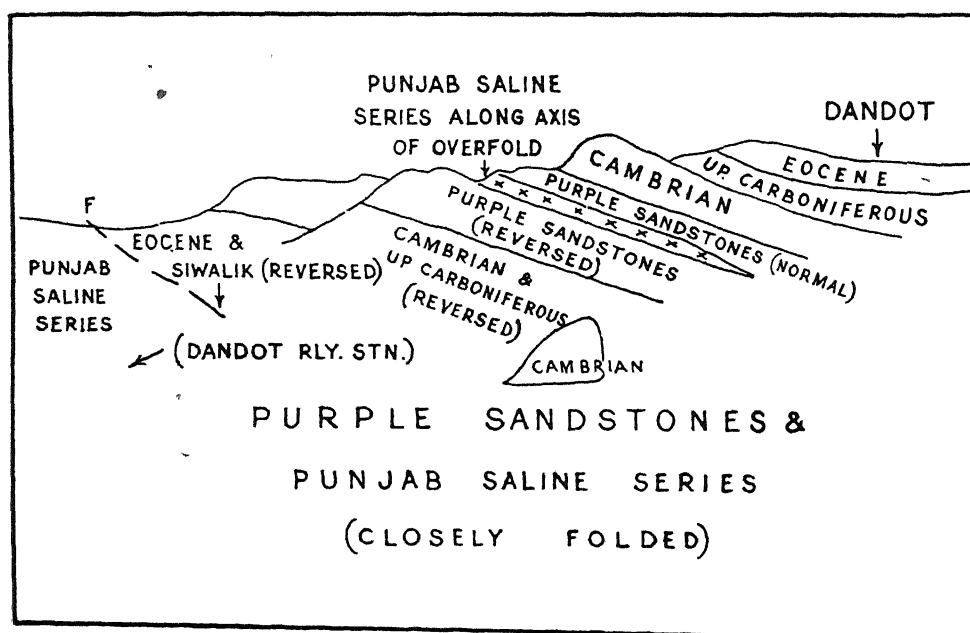
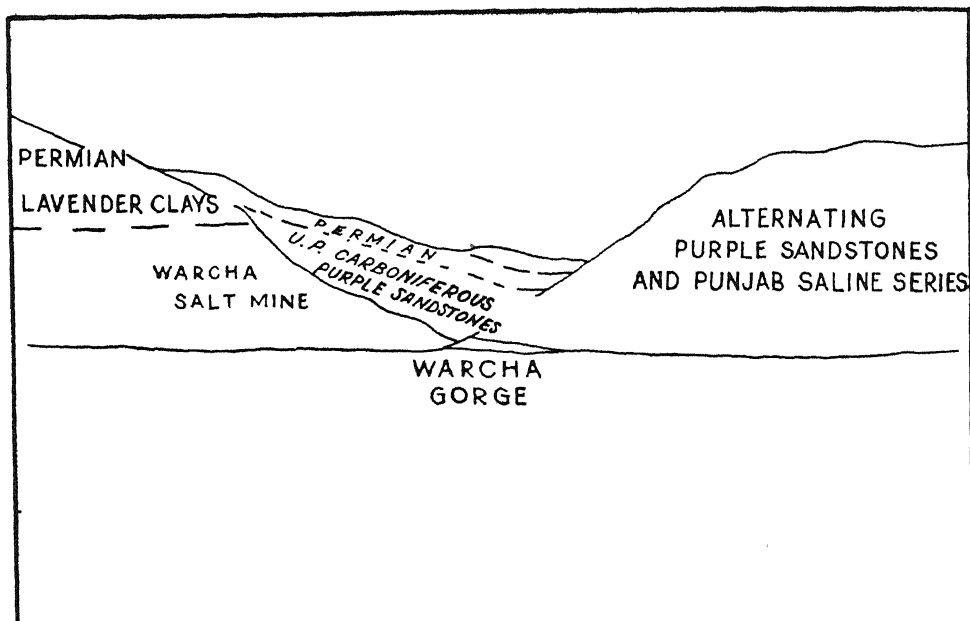




FIG. 1.—ENTRANCE TO WARCHA MANDI GORGE.



FIG. 2.—SALT RANGE SCARP BELOW DANDOT.

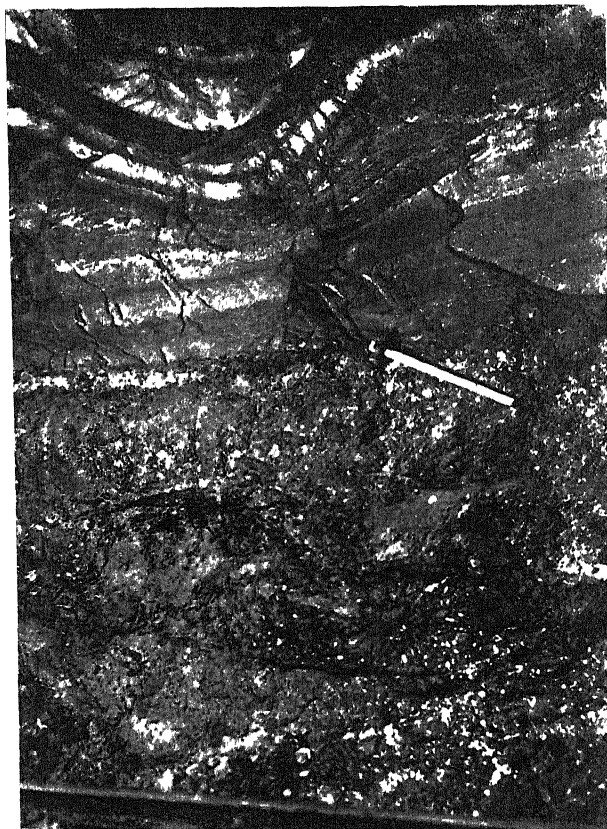


FIG. 1.—ROCKSALT, ETC. OVERLYING SUB-RECENT DEBRIS, WARCHA SALT MINE.

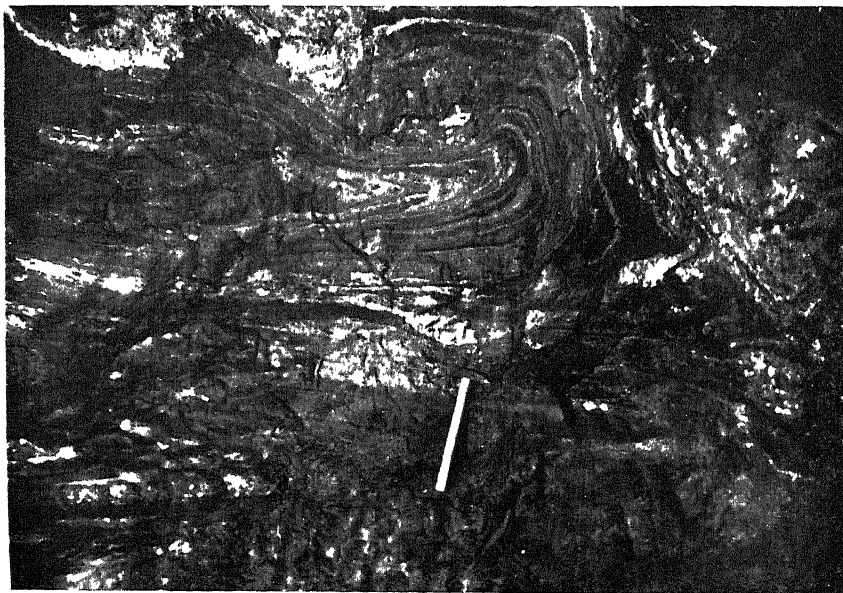
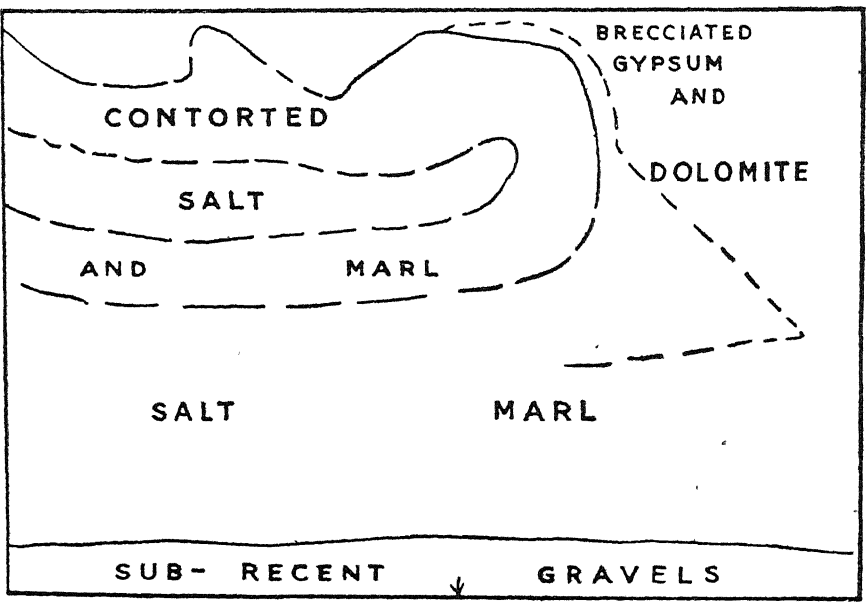
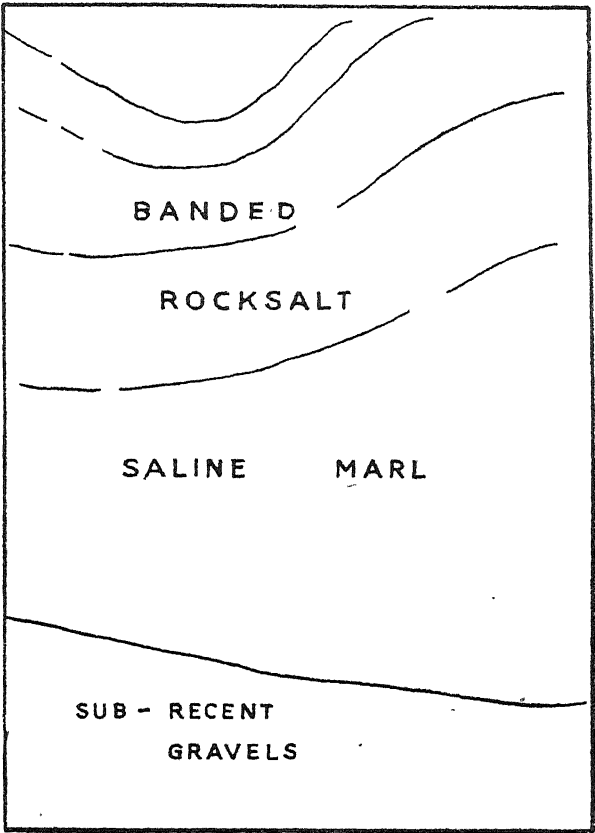


FIG. 2.—DITTO, OVERFOLDED.



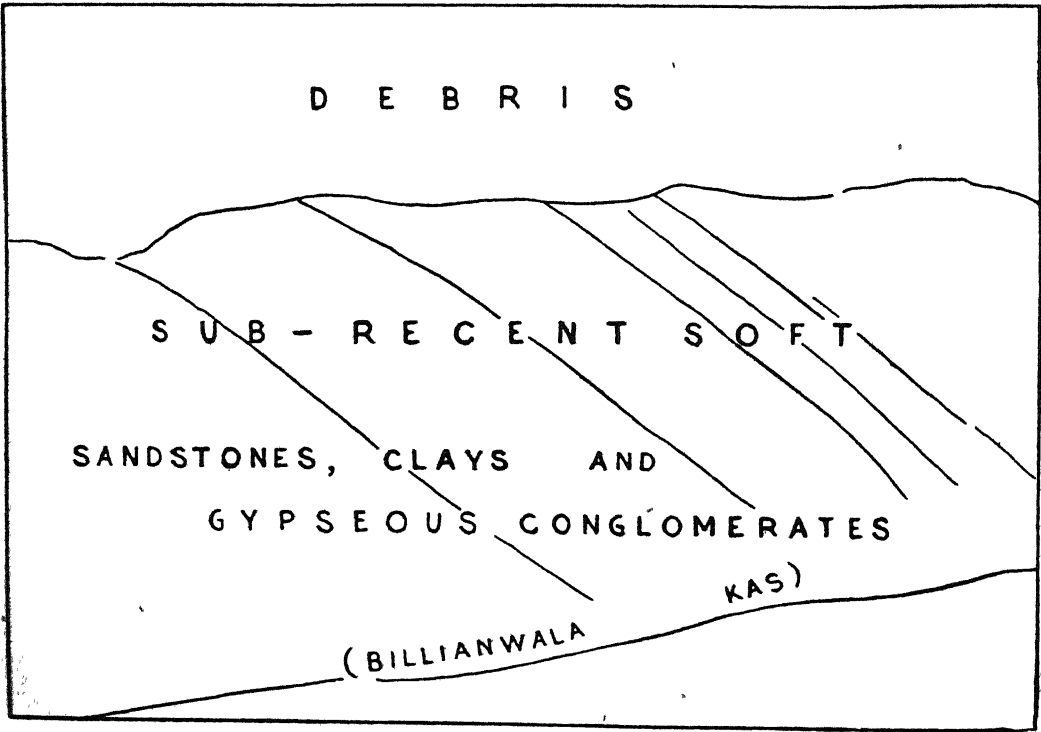
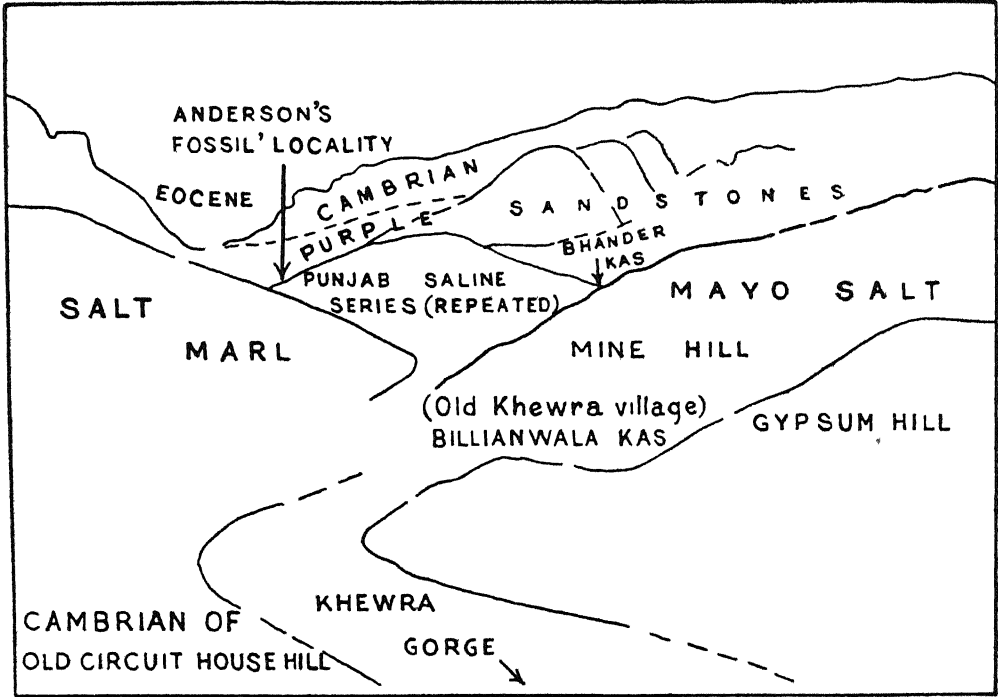




FIG. 1.—THE KHEWRA GORGE.

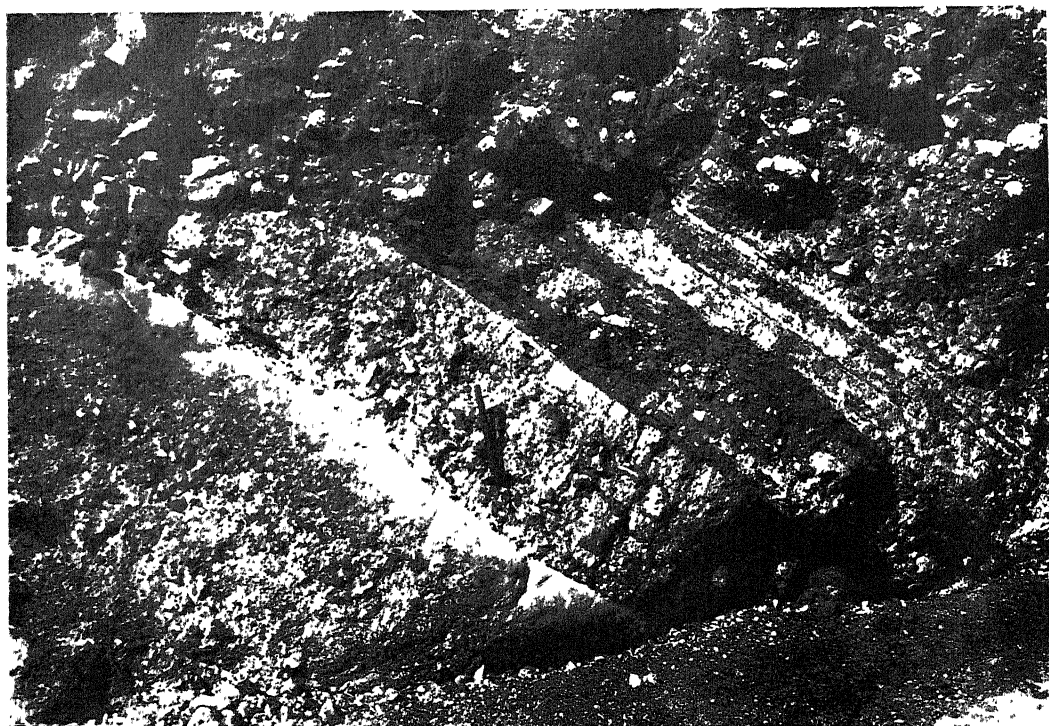


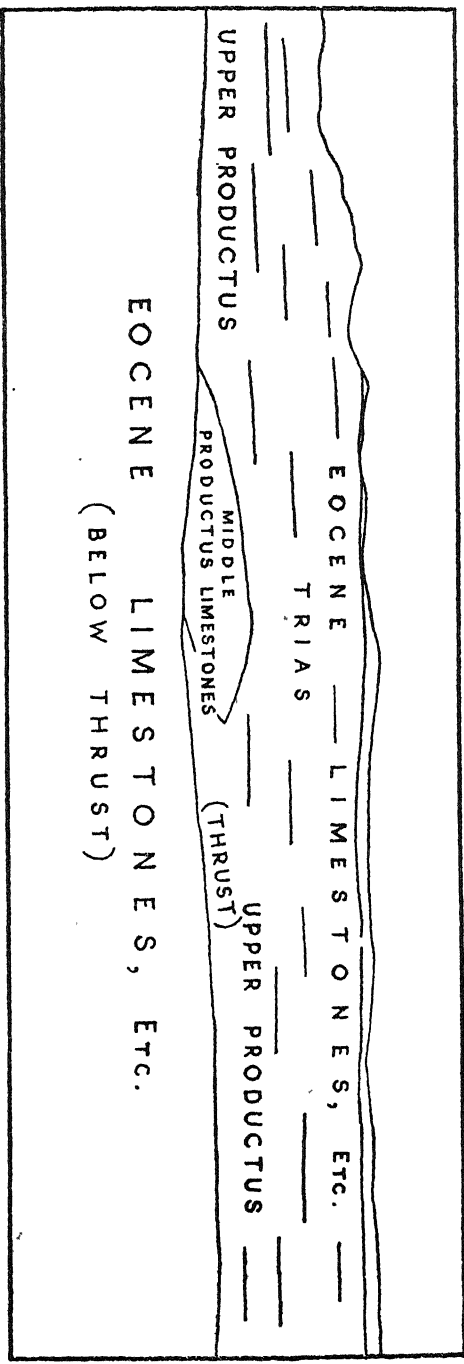
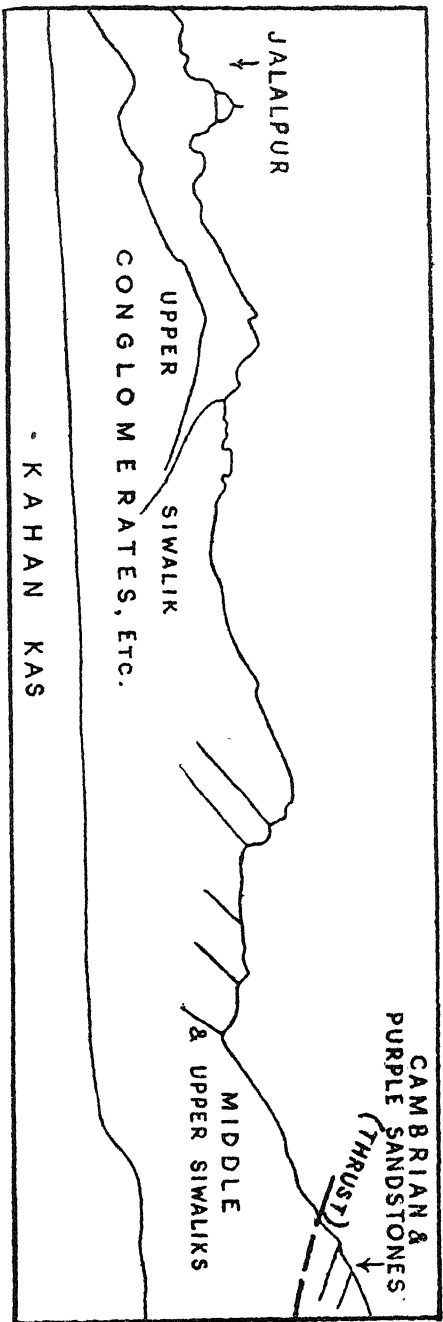
FIG. 2.—SUB-RECENT BEDS IN BILLIANWALA GORGE, KHEWRA.



FIG. 1.—THE SCARP NEAR JALALPUR.



FIG. 2.—SEQUENCE REPEATED BY THRUSTING NEAR GHANER.



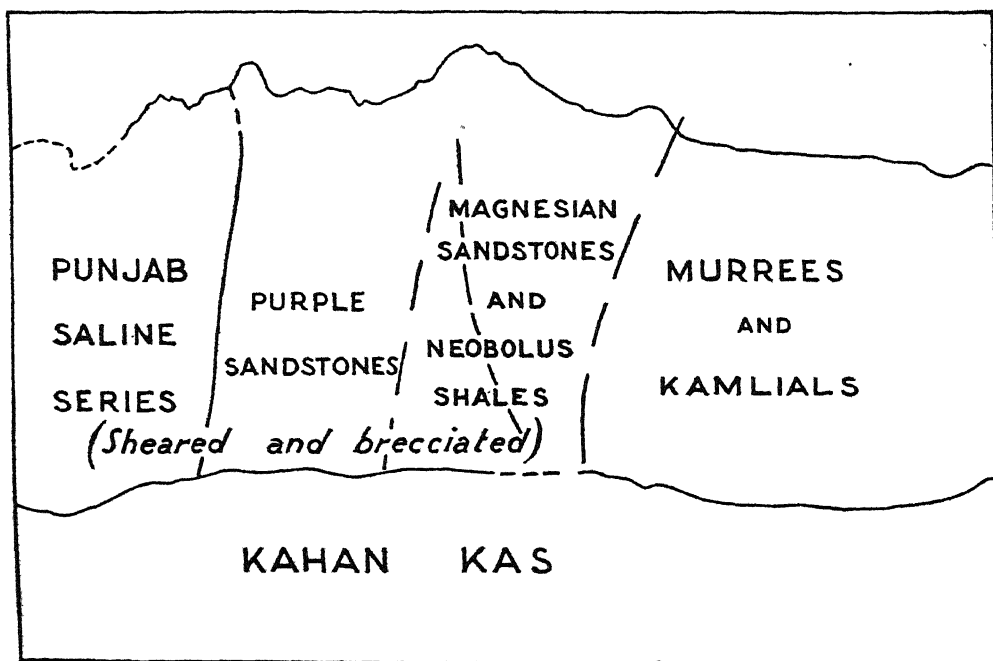
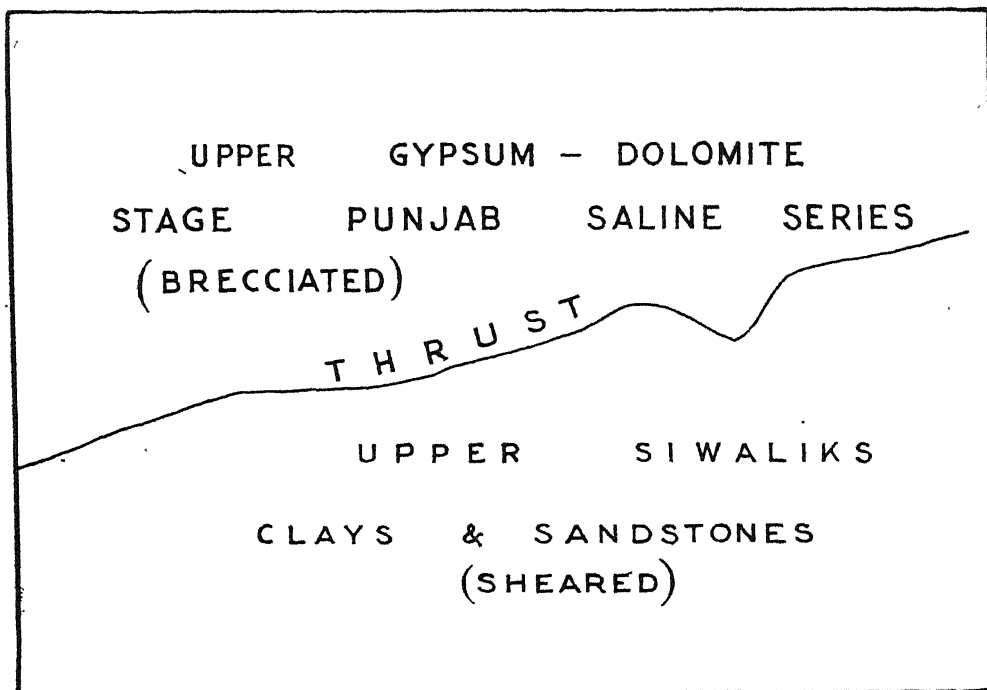




FIG. 1.—THRUST AT CHITTI, NEAR JALALPUR.

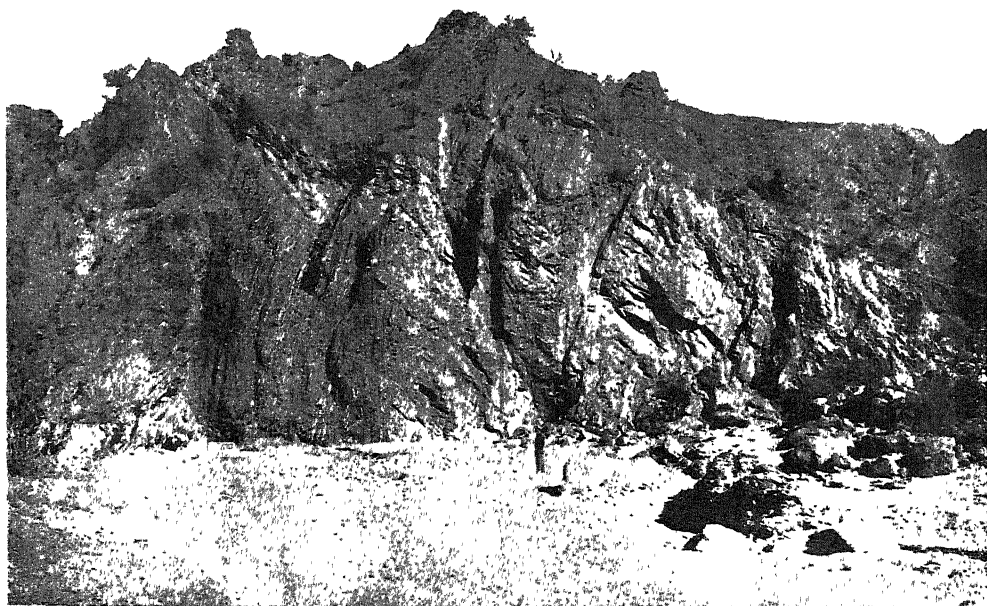


FIG. 2.—FAULT ZONE NEAR JALALPUR.

MICROFOSSILS FROM CORES RECOVERED FROM BOREHOLES IN THE SALINE SERIES AT KHEWRA IN THE PUNJAB SALT RANGE*

By

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RESEARCH STUDENT, UNIVERSITY OF LUCKNOW

(With 1 table, 2 plates and 32 figures in the text)

(Received 19 December 1945)

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ABSTRACT.

The present paper is divided into two parts, the first dealing with microfossils prepared from a core from an exploratory drift north of the Bhandar Kas, Khewra; and the second with those recovered from core samples from a boring below the South Pharwala Section of the Mayo Salt Mine at Khewra. The material from near the Bhandar Kas is a sample of Salt-and-Marl registered as S.R.E. 34. It was collected by the Salt Range Excursion party led by Mr. E. R. Gee in November 1944 and sent for examination to Professor Sahni. The cores from the Mayo Salt Mine were sent by Mr. B. S. Lamba in two instalments, three of them in February and fourteen in May, 1945. The entire material was entrusted to me for microfossil analysis by Professor Sahni.

Out of the seventeen samples from the Mayo Mine eight were selected for examination. The samples were dissolved either in filtered distilled water, if they were cores of Salt-and-Marl; or in filtered dilute hydrochloric acid, if dolomitic. All possible precautions were taken to avoid extraneous contamination.

The structure of most of the plant microfossils indicates that they definitely belong to Gymnosperms and Angiosperms. Even others, excluding the pieces of chitin, are pieces of tissues decidedly belonging to some vascular plants. All these represent types of life that cannot have existed before Middle Mesozoic times. Thus they afford strong evidence in favour of the post-Cambrian hypothesis for the age of the Salt Range Saline Series.

*This work was carried out with the aid of a research scholarship from the Burmah Oil Company, Ltd.

PART I.

Core from an Exploratory Drift north of the Bhandar Kas, Khewra.

INTRODUCTION.

In their investigation of rock specimens from the Salt Range Saline Series, Professor Sahni and Mr. B. S. Trivedi (*Sahni, B. April 1944, p. 462: September 1944, pp. 49-66. Sahni and Trivedi, 1943, pp. 25-26: 1944, p. 54*) reported microfossils of a type found only in strata younger than the Middle Mesozoic. This was an almost decisive point in favour of the post-Cambrian hypothesis for the age of the Saline Series, had not the *in situ* nature of these samples been called into question by some geologists. Accordingly, a search for microfossils was made in some rock samples collected during the Salt Range Excursion led by Mr. E. R. Gee in November, 1944. I describe briefly below some of the microfossils found in a sample of Salt-and-Marl registered as S.R.E. 34, comprising a number of small cores about 1.5 to 1.75 inches long and 1.75 inches in diameter. Earthy marl or 'kallar' found together with salt is responsible for the dirty look of the cores, the quantity of 'kallar' contained determining the degree of dirtiness and opacity. In colour the cores are either reddish or greyish white. One of the cores also contains small white pieces of gypsum. The locality of these cores is given by Mr. Gee in a letter to Professor Sahni dated the 3rd September 1945 as follows:—"From the bore-hole of the Saline Series in the exploratory drift just north of the Bhandar Kas, Khewra".

TECHNIQUE.

Special precautions were taken throughout the work to avoid any source of atmospheric contamination. All the apparatus used was of glass and metal, anything made of wood and cork being avoided. A 250 cc. flask with a long narrow neck, after cleaning with chromic acid and washing thoroughly with filtered distilled water, was filled with filtered distilled water up to a level reaching near the top of its neck. A narrow-necked flask was chosen so that the light microfossils that float up to the surface of the saline solution should be confined to a very small area at the top of the neck from where it is easy to suck them out with a pipette. The filter paper used for all the filtrations was chemically prepared paper. Two clean pairs of tongs were used to rotate the rock sample in a flame, so that the points left unexposed while holding the sample with the first pair of tongs, were exposed to the flame on holding the sample with the second. In case a gas burner was not available a spirit lamp was used but instead of cotton-wool, a wick of glass-wool was used, because it

was found that burnt fibres of cotton-wool were sometimes thrown up by the flame and in the end were liable to be mistaken for carbonised microfossils. About 75 grams of pieces of the core, small enough to pass down the neck of the flask, were thoroughly cleaned with a hard brush, rotated one by one in a flame and dropped immediately into the flask. A few drops of filtered aqueous safranin were added to the solution to stain any organic particles released, which were then sucked out by a pipette and examined under the microscope.

To handle the microfossils the use of a brush was avoided as the minute particles might be lost in the bristles. Instead, a micropipette was used. This is a small narrow glass tube, on one end drawn into a fine jet and on the other connected by a piece of rubber tubing (conveniently a bicycle valve tube) to a small glass mouth-piece. By sucking at the mouth-piece, while the jet is held in the solution, any small object can be picked up and transferred to a slide by gently blowing it out.

DESCRIPTION.

A. Microfossils from Salt-and-Marl.

(Text-figs. 1-12; Plate 1, Photos. 1-7).

The microfossils can be classified into five different groups:

(a) *Tracheids and woods* (not carbonised). A large number of these have been observed; a few notable ones are:—

(1) An incomplete gymnospermic tracheid *ca.* 640 microns long and on the average 36 microns wide (Text-fig. 1; Photos. 1, 2) broken near one end and bent twice along its length. Pits bordered, circular or elliptic, as a rule uniseriate, contiguous or separate, 12×12 to 21×15.5 microns; pores 4 to 6.5 microns in diameter. Rims of Sanio not visible.

(2) A long vessel broken into two pieces (Text-fig. 2). Average width 10.4 microns. The wall shows reticulate thickenings and at places the network is so close that it gives the appearance of bordered pits. Such 'pittings' are visible at least at four places in the bigger piece.

(3) A small piece composed of three incomplete woody cells (Text-fig. 3). One of the cells shows simple, circular pits with an average diameter of 2 microns.

(4) A piece of wood (Text-fig. 4) composed of about a dozen incomplete bluntly tapering tracheids about 8 microns in width. Some tracheids show simple, elliptical, separate, uniseriate pits 3×1 microns in size; others show pits in sectional view looking like pores in their walls. All the walls have a middle lamella running throughout their length.

(5) A piece of wood (Text-fig. 5) with part of an 8-celled medullary ray only one cell deep. Tracheids long, tapering towards the ends. Width varying from 7.8 to 20.8 microns. Pits bordered, circular, separate, varying in size from 6 to 13 microns; pores 2 to 5 microns in diameter. Pits in the field separate, 1-3 in each field, size variable. No rims of Sanio visible.

The affinities of this piece of wood are impossible to establish with these meagre data. The bordered pits and the compact tracheids indicate that it is one of the conifers.

(6) A piece of wood broken into two bits (Text-fig. 6; Photo. 3) composed of long and broad, thick-walled cells; each cell *ca.* 15 microns wide. Pits simple, circular, separate, 1.5 to 2 microns in diameter, scattered. The simple pits suggest that it may be regarded as a piece of angiosperm wood.

A few of the other pieces of wood which are not described here, are represented by text-figures 7-10 and photomicrographs 4 and 5.

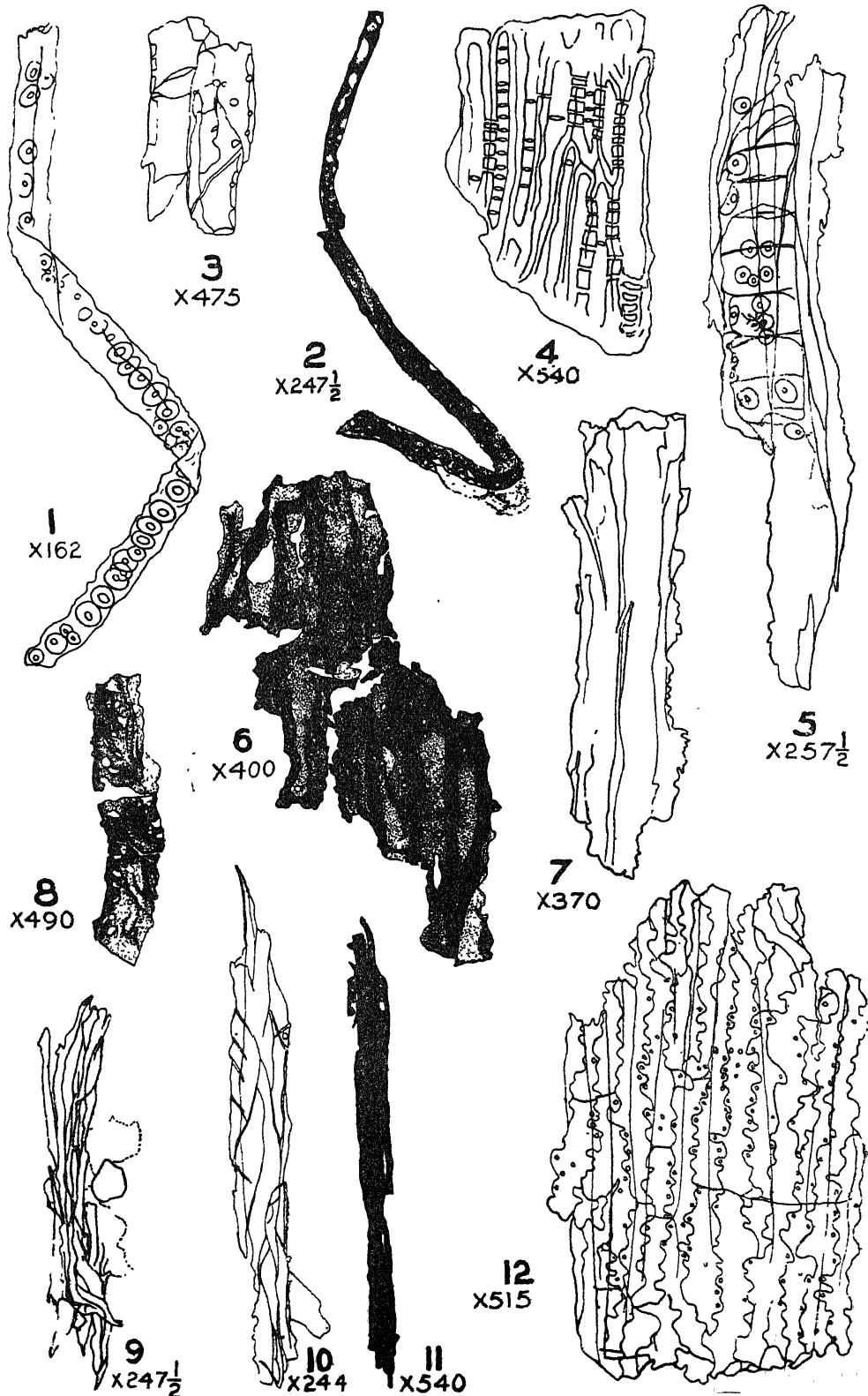
(b) *Pieces of carbonised wood.* Three shreds of carbonised wood have been found. One of these (Text-fig. 11; Photo. 6) is a piece 125 microns in length. Width varying from 5.2 to 9 microns. The woody nature is apparent from the long tracheid-like cells, between which are indications of medullary rays, shown by long white strips. These blank spaces might also be due to the wood cells having split apart longitudinally during preservation.

(c) *Fibres.* A large number of fibres have been met with out of which a few were mounted in Canada balsam.

(d) *Cuticles.* Two pieces of cuticle were found. One of these (Text-fig. 12; Photo. 7) evidently belongs to some grass. It is composed of long sinuous-walled cells (ripple-walled cells of Arber, 1934, *p.* 301). On changing the focus a few straight-walled parenchymatous cells of the layer underlying the cuticle also become visible. Maximum width of the sinuous-walled cells 10.4 microns, minimum 3.9 microns. On the cuticle are circular areolae ('ponctuations cuticulaires' and 'ponctuations profondes' of Prat, 1932, *pp.* 192-193) *ca.* 1.5 microns in diameter. Stomata are not seen.

Text-figures 1-12. Camera lucida sketches of microfossils from a core of salt-and-marl (S.R.E. 34) from an exploratory drift near the Bhandar Kas, Khewra. Coll: E. R. Gee and party.

1. A gymnosperm tracheid with bordered pits. 2. A vessel showing reticulate thickening of its wall. 3. Woody cells with simple pits. 4. A piece of wood with uniseriate, elliptical, simple pits. 5. A piece of wood with a multicellular medullary ray and bordered pits. 6. A piece of wood with thick walled vessels bearing simple pits. 7-10. Pieces of wood. 11. A piece of carbonised wood. 12. A grass cuticle with sinuous-walled cells and circular areolae.



The ripple-walled cells and the circular areolae definitely prove that this piece of cuticle belongs to one of the Gramineae. Further affinities, however, cannot be established as no stomata have been preserved.

(e) *Animal microfossils*. Five pieces of animal tissue have been found. Four of them seem to be pieces of chitin. They are dark-coloured porous fragments. The fifth piece has been identified by Mr. M. S. Mani of the St. John's College, Agra as a fragment of an antenna of some Arthropod (*Mani* 1946, *fig. 7*).

DISCUSSION.

The pieces of wood and tracheids found show characters mostly of Gymnosperms and Angiosperms. The well developed bordered pits in tracheid No. 1 (Text-fig. 1; Photos. 1, 2) and the piece of wood No. 5 (Text-fig. 5) suggest very strongly that these belong to some conifers, a highly evolved group of the Gymnosperms. Other pieces of wood, bearing simple circular pits (*e.g.* Text-figs. 3, 4, 6) belong to Angiosperms, the highest evolved phylum of the plant world.

Gymnosperms are not known to have occurred earlier than the Devonian. If *Homoxylon rajmahalense* (*Sahni*, 1932) is not regarded as the earliest Angiosperm (because there is some doubt with regard to the real horizon from which this fossil was collected), the earliest clear record of Angiosperms becomes Lower Cretaceous, from which horizon M.C. Stopes has described the oldest known undoubted Angiosperms, *Aptiana radiata* and other dicotyledonous woods (*Stopes*, 1912). Regarding the general appearance of these early Angiosperms she writes, "They appear also to have worn much the same guise as they still present to the world, even in the earliest strata in which they have been found" (*Stopes*, 1912, *p. 75*). This explains the rather modern look of the angiospermic woods and cuticles found as fossils.

The piece of cuticle (Text-fig. 12; Photo. 7) with its ripple-walled cells and the circular areolae cannot belong to anything but one of the Gramineae, again an angiosperm family.

The presence of woods carbonised and otherwise, and of the woody fibres, bespeaks the vascular nature of the plants to which they belonged. "The oldest vascular plants at present known with any completeness are those from the Upper Silurian of Victoria" (*Cookson*, 1936) from which is described *Baragwanathia longifolia* (*Lang and Cookson*, 1935). Even this, however, does not carry matters as far back as the Cambrian or pre-Cambrian. Thus these microfossils bear no evidence in favour of the Saline Series being of Cambrian or pre-Cambrian age, and as the choice lies only between the Early Palaeozoic and Early Tertiary (Eocene), the evidence points definitely to the latter age.

PART II.

Core samples from a boring below the South Pharwala Section of the Mayo Salt Mine, Khewra, Salt Range.

INTRODUCTION.

In February 1945, as a result of boring, 231 feet of rock-core were recovered from Chamber 10 in the South Pharwala section of the Mayo Salt Mine, Khewra. A detailed description of the sequence of beds met with has been given by Mr. B. S. Lamba, Manager, Mayo Salt Mine (*Lamba 1946*). Anticipating that these cores would yield microfossils interesting from the point of view that they might throw some light on the age of the Saline Series, Mr. Lamba sent three of them from depths of 110, 117 and 125 feet to this laboratory in February, 1945 for microscopic examination. Later, in May 1945, fourteen more samples from various depths were received.

So far eight cores have been examined and the microfossils found in them are described briefly in this note.

TECHNIQUE.

The method employed in the examination of these samples is to dissolve the rocks in suitable solvents and then to examine drops of the solution under a microscope. The core samples examined fall under two categories, dolomitic rocks and rock-salt. The former were dissolved in 4% filtered hydrochloric acid and the latter in filtered distilled water. Special care was taken to avoid any atmospheric contamination. In case of the rock samples from depths of 145 and 149 feet, an electric centrifuge was used to concentrate the minute fossils at one place, which very much facilitated their examination. Thin hand sections from these cores were also prepared so that the rock matrix could be examined microscopically.

DESCRIPTION.

(*Text-figs. 13-32; Plate 2, Photos. 8-18*).

A condensed summary of the microfossil finds is given below:—

<i>Depth in feet.</i>	<i>Description of the rock.</i>	<i>Microfossils observed.</i>
110	Dolomite, dark grey, containing gas and oil.	1 woody fibre. 3 pieces of wood; one of these (Text-fig. 13; Photo. 8) shows a single circular bordered pit.

<i>Depth in feet.</i>	<i>Description of the rock.</i>	<i>Microfossils observed.</i>
117	Dolomite mottled with saline pellets giving it conglomerate appearance or breccia.	5 woody fibres. 5 pieces of wood. One of these (Text-fig. 14; Photo. 9) bears 2 bordered pits, another (Text-figs. 15, 16; Photos. 10, 11) shows medullary rays crossing the tracheids with a large number of bordered pits. 1 piece of cuticle (Photo. 15).
125	Dolomite mottled with saline pellets and white salt in cracks. (Bituminous).	1 long animal hair-like structure with a swelling at one end (Text-figs. 21, 22). 1 piece of wood (Text-fig. 17) bearing 3 uniseriate, separate, circular bordered pits. 1 fibre. 1 piece of membrane with two thick structures attached, one (Text-fig. 23) cylindrical with holes in it and the other probably a piece of chitin (Text-fig. 24).
143	Grey salt	.. 7 fibres. 1 piece of chitinous membrane. 1 thick structure like a piece of animal hair. 1 group of fibres. 6 shreds of wood (Text-figs. 25, 28, 29; Photo. 16). The piece in Fig. 25 shows simple pits.
145	Light grey salt	.. 8 pieces of wood (Text-fig. 26). 1 collection of fibres looking like a small dehiscent capsule with 4 valves. 1 piece of membrane. 7 fibres. One of these in slide No. 84 shows small simple pits. 1 spoon-shaped piece with a row of bead-like structures on one side (Photo. 18).

<i>Depth in feet.</i>	<i>Description of the rock.</i>	<i>Microfossils observed.</i>
149	Dolomite, gypsum and salt mixed up with slickensides and shining dark pellets.	About a dozen fibres. 3 pieces of wood, one tiny black shred with simple pits (Text-fig. 18; Photo. 12). 2 small black round spore-like bodies (Text-fig. 19; Photo. 13). 1 membranous cuticle-like structure overlaid by a piece of wood (Text-fig. 20; Photo. 14).
229	Pinkish marl with salt ..	1 long spine with tiny hairs over its surface (Text-fig. 32). 1 long multicellular structure like an animal hair (Text-fig. 31). 2 pieces of wood (Text-figs. 27, 30; Photo. 17). The piece in text-fig. 27; Photo. 17 shows 2 round bordered pits.
231	Gypsum with blue clay and marl.	No microfossils observed.

It is apparent from the above summary that a large number of microfossils have been found. A few of them which show some important details of structure are described below.

A table from Mr. Lamba's paper (*Lamba, 1946*) showing the section of the borehole is also inserted here for ready reference. The depths at which microfossils have been found are given in the footnote below the table.

P. Microfossils from dolomitic rocks.

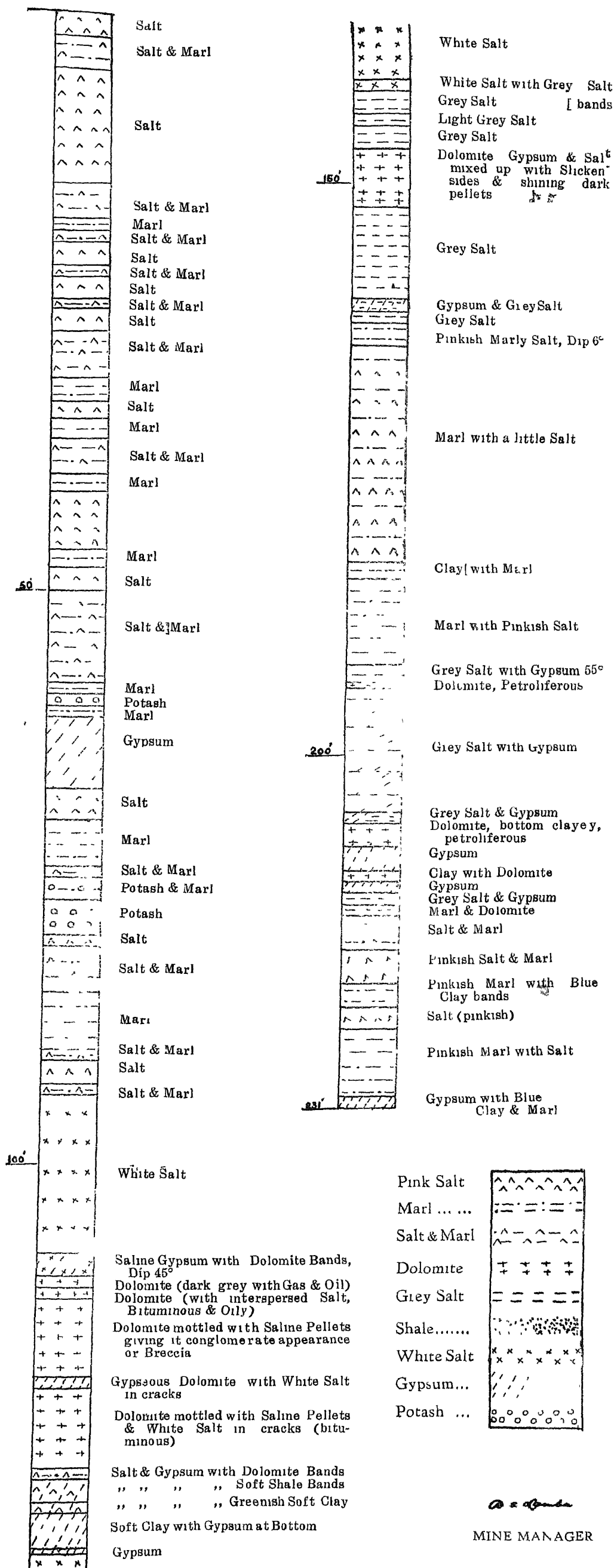
(110', 117', 125' and 149').

(a) Pieces of wood.

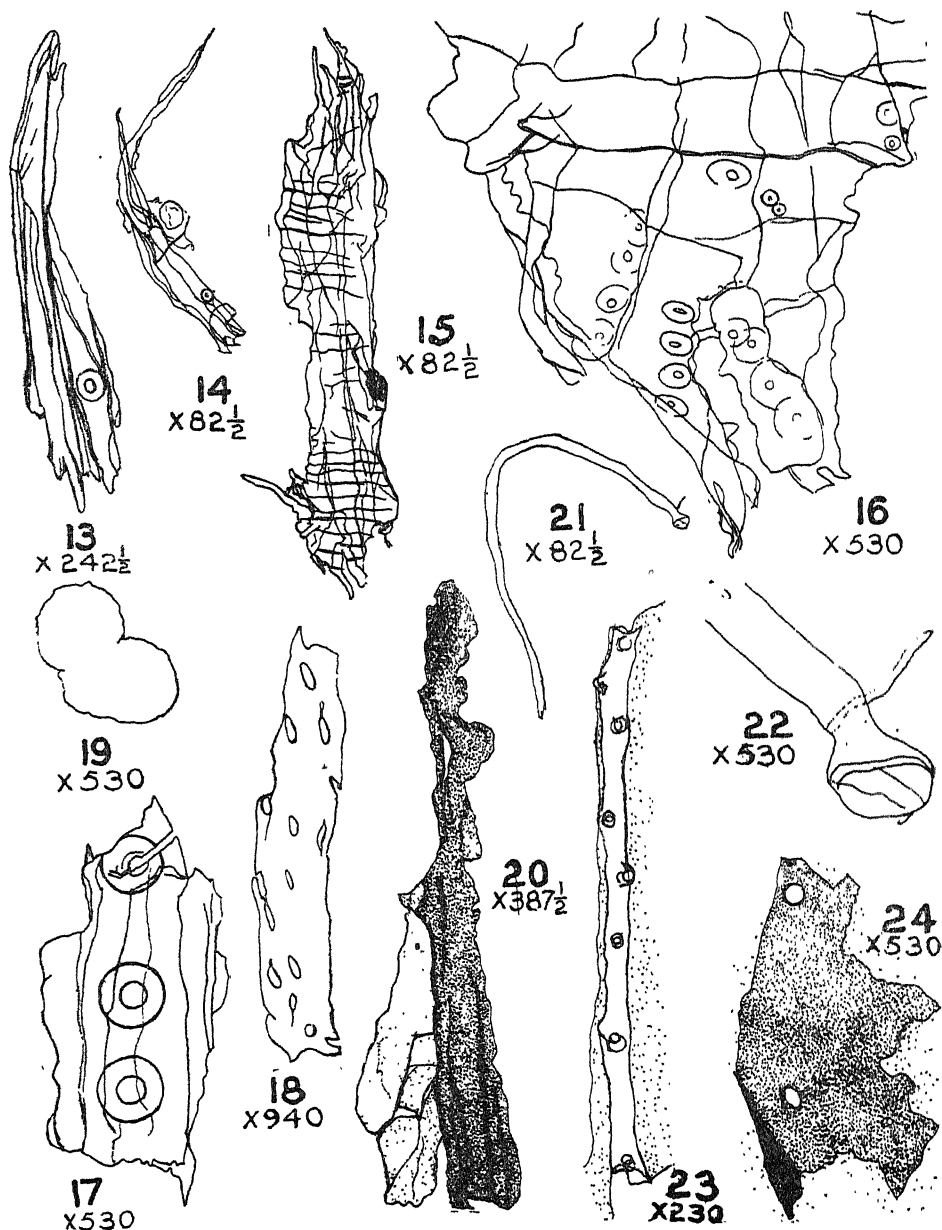
(1) A small shred of wood (Text-fig. 13; Photo. 8) from 110 feet. It is composed of two incomplete tracheids, the shorter one bearing a single, circular bordered pit 15 microns in diameter with a pore of 6 microns.

(2) A piece of wood comprising long tapering tracheids (Text-fig. 14; Photo. 9) from a sample of dolomite mottled with saline pellets from a depth of 117 feet. At the lower end (Text-fig. 14) is visible a structure looking very much like a big incomplete bordered pit. Near this structure towards the

SECTION OF BORE HOLE \
IN CHAMBER 10. S. PHARWALA
MAYO SALT MINE, KHEWRA
VERTICAL SCALE 1"=98'



Microfossils have been recovered from cores from depths of 110, 117, 125, 143, 145, 149 and 229 ft.



Text-figures 13-24. Camera lucida sketches of microfossils from samples of dolomitic rocks from a boring below the south Pharwala section of the Mayo Salt Mine. Coll: B.S. Lamba.

13. A shred of wood bearing a round bordered pit. Depth 110 ft. 14. A piece of wood. Depth 117 ft. 15. A piece of wood with medullary rays. Depth 117 ft. 16. A portion of the above magnified, showing bordered pits. 17. A piece of wood with bordered pits. Depth 125 ft. 18. A piece of carbonised wood with simple pits. Depth 149 ft. 19. Two fungal spores. Depth 149 ft. 20. A piece of cuticle overlaid by a piece of wood. Depth 149 ft. 21. An animal hair-like structure. Depth 125 ft. 22. A portion of the above magnified. 23. A rod-like animal microfossil from the same depth. 24. A piece of chitin from the same depth.

middle is a slightly pressed bordered pit 13×10.5 microns in diameter with a central pore *ca.* 5×4 microns across.

(3) Another piece of wood from the same depth (Text-figs. 15, 16; Photos. 10, 11). It is made up of long and tapering tracheids of an average width of 15 microns. Pits bordered, uniseriate, circular but slightly pressed, 6.5 microns to 9 microns in diameter; pores 1.5 to 2.5 microns. Two multi-cellular medullary rays are visible in radial section crossing the tracheids near the two ends of the piece of wood. One of these is 8-celled and the other is 10-celled.

(4) A shred of gymnospermic wood composed of parts of three tracheids (Text-fig. 17) from a sample of dolomite with saline pellets from a depth of 125 feet. The tracheid in the middle bears three large round, uniseriate, separate bordered pits about 15.6 microns in diameter with the pore *ca.* 6 microns across.

(5) A small shred of wood from the dolomite of 149 feet depth (Text-fig. 18; Photo. 12). The wood is almost black due to carbonisation. It bears about a dozen simple, elliptical pits *ca.* 3×1.5 microns in size. The simple pits indicate it to be a piece of some angiospermic wood.

(b) Fibres.

A very large number of fibres were found but only a few of them have been mounted. There being nothing very important about their structure that would help in establishing their affinities, a detailed description is not given.

(c) Other plant tissues.

(1) Two dense black round spore-like bodies (Text-fig. 19; Photo. 13) from the sample from a depth of 149 feet. They have small projections on the surface, giving it a rough appearance. One 'spore' is circular in outline with a diameter of 21 microns while the other is more ovoid being 29×21 microns along the two axes. Most probably these are some fungal spores.

(2) A piece of cuticle overlaid on one side by a piece of wood (Text-fig. 20; Photo. 14) from the same sample. The dark long piece looks woody being thick and almost opaque. The membranous piece of cuticle shows some squarish marks on it which suggest its cellular nature. The thin and delicate texture also indicates it to be a piece of some cuticle.

(3) A piece of cuticle (Photo. 15) from 117 feet. On one side (top of photo.) the margin is frilled like the sinuous wall of a cell belonging to the cuticle of a grass. An isolated long and narrow cell with such sinuous walls is also seen lying on the larger cuticle near the lower right-hand corner of the photograph.

The presence of these sinuous-walled cells, typical of the cuticle of grasses, indicates that this piece belonged to one of the Gramineæ.

(d) *Animal microfossils.*

(1) A long hair-like structure (Text-figs. 21, 22) from a piece of dolomite from a depth of 125 feet. It is a long, cylindrical, uniformly thick fibre, abruptly broken at one end and swollen at the other. The swollen end had a complete round shape but shrivelled up while it was being mounted. According to Mr. Mani it is some sort of an animal hair but does not belong to an Arthropod.

(2) A fine transparent membrane from the same sample. It shows two notable structures on its surface.

The first is long and rod-like (Text-fig. 23) bearing circular holes about 5 microns in diameter, placed approximately 35 microns apart. Each hole is situated on a little raised knob-like area resulting in the irregular outline of the rod-like structure.

The other is an irregular piece of chitin (Text-fig. 24) with two holes of about 5 microns diameter. The lower hole seems to bear a short pointed papilla.

The nature of both these structures is obscure.

C. Microfossils from samples of Salt-and-Marl.

(143', 145' and 229').

The fossil remains from these cores are described under the same four heads as for the microfossils from the dolomitic rocks.

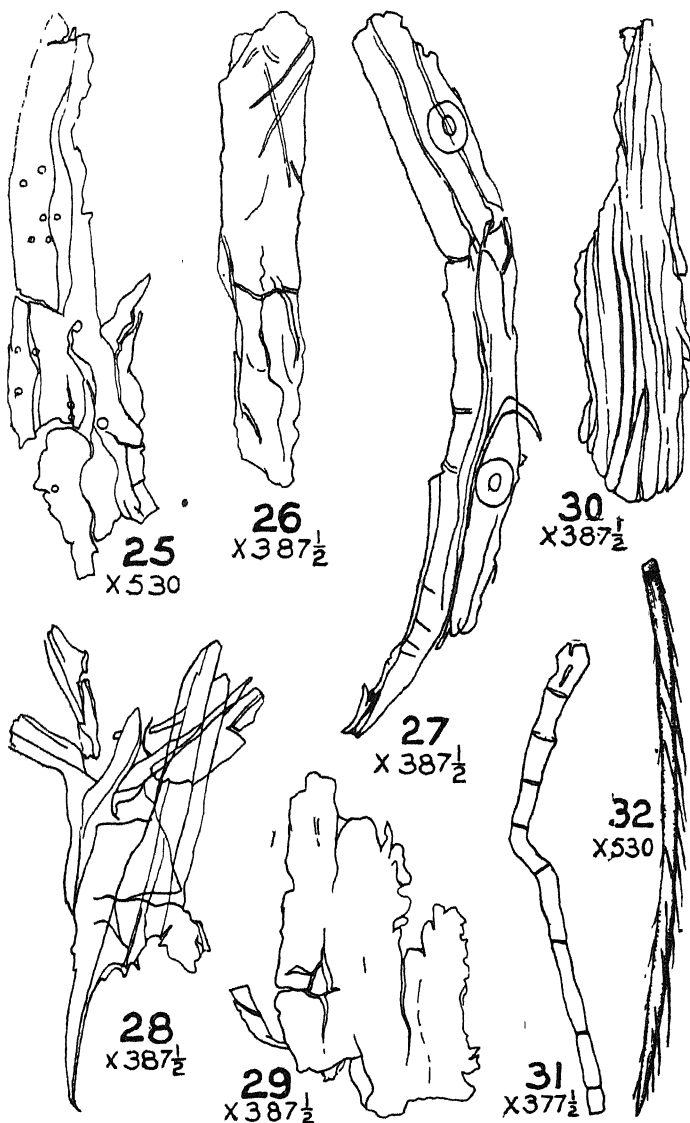
(a) *Pieces of wood.*

The more important are:

(1) A piece of wood from a sample of grey salt from a depth of 143 feet (Text-fig. 25; Photo. 16). It is broken up by many cracks. The vessels are long and uniformly thick and bear simple, circular pits about 2 microns in diameter. The presence of long vessels and circular pits shows that it is a piece of some angiospermic wood.

(2) A wood cell from the light grey salt from a depth of 145 feet. There are no pits visible but the markings on the surface (Text-fig. 26) suggest the spiral texture of the lignified membrane.

(3) A piece of gymnospermic wood (Text-fig. 27; Photo. 17) from a sample of pinkish marl with salt from a depth of 229 feet. It comprises two pieces of



Text-figures 25-32. Camera lucida sketches of Microfossils from samples of Salt-and-Marl from a boring below the South Pharwala Section of the Mayo Salt Mine. Coll: B. S. Lamba.

25. A piece of wood with simple circular pits. Depth 143 ft. 26. A wood cell showing the spiral texture of the lignified membrane. Depth 145 ft. 27. A piece of wood with 2 bordered pits. Depth 229 ft. 28-30. Pieces of wood, 28 and 29 from depths of 143 ft., 30 from 229 ft. 31. A jointed hair-like animal structure. Depth 229 ft. 32. Part of the hair of a Dermestid larva from the same depth.

tracheids one about 11 and the other about 13 microns in width. Two slightly ovoid, separate, bordered pits *ca.* 15×12 microns with pores *ca.* 5×3 microns in diameter are borne by the wider tracheid.

Some other pieces of wood not described here are represented by text-figures 28, 29 and 30.

(b) *Fibres.*

A large number of fibres were met with but as before, they are not described here in detail.

(c) *Other plant tissues.*

A club-shaped vesicular membrane (Photo. 18) from light grey salt from a depth of 145 feet. It is swollen on one side, gradually narrowing towards the other. On the swollen end is attached a short structure like a broken stalk. A little away from this end is a thick dark rim running across the 'vesicle'. Lying longitudinally on one side are a number of bead-like structures in a row. There is also a fold running longitudinally along its middle. It suggests a membrane folded into a vesicular structure in the cavity of which are deposited these bead-like things which might be spores. The precise nature of this structure is not known.

(d) *Animal microfossils.*

(1) A long, cylindrical, jointed, hair-like structure (Text-fig. 31) from a sample of pinkish marl with salt from a depth of 229 feet. The filament is thicker at one end, gradually narrowing towards the other. It is composed of nine segments, the last one on the narrow end being incomplete. Mr. Mani suggests that it might possibly be a piece of the terminal fila situated posteriorly on the abdomen of an insect.

(2) A long, stiff hair (Text-fig. 32) bearing minute bristles all over its surface, from the same sample. Mr. Mani has identified it as the hair of a Dermestid larva.

DISCUSSION.

The microfossils found come not only from samples of Salt and Marl but also from dolomitic rocks, in which the foreign particles could not have been easily washed in after the rocks had once been formed. The question of atmospheric contamination should not arise in the case of samples coming from depths like 229 feet. Moreover, small organic fragments were often seen coming off from the rocks while they were being dissolved by the solvent.

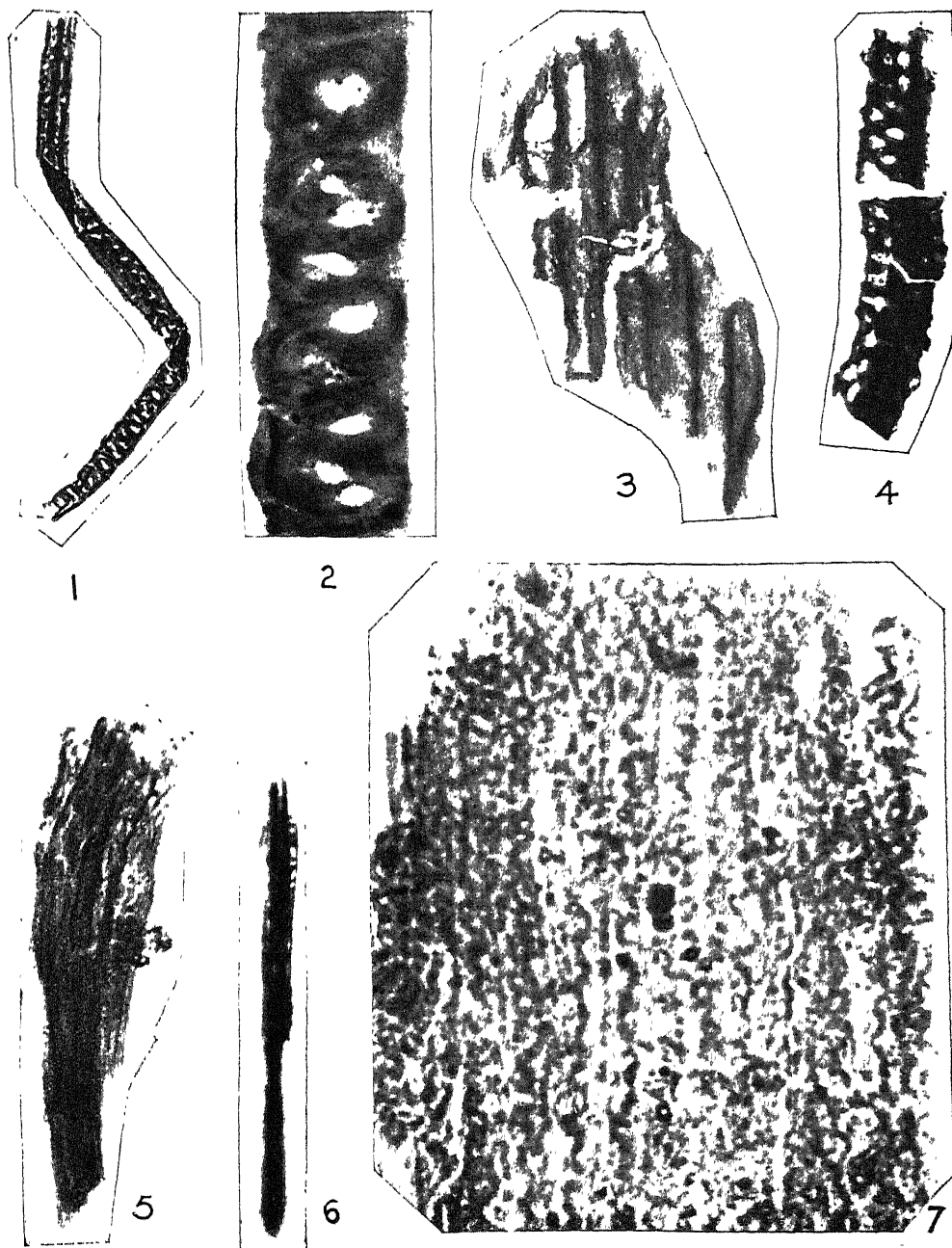
From the list of microfossils given above it can be seen at a glance that the samples examined contain entombed within themselves a wealth of pieces of wood and fibres together with minute pieces of animal tissue like chitin and hairs. On the advent of the land habit the plants were confronted with the problem of adaptation to the meagre supplies of water. As a result was developed a cuticle to check desiccation. Another change in the plants was the development of a vascular system that effected the circulation of water absorbed from the soil and also served as the mechanical system. "The plants from Cambrian, Ordovician and Silurian sediments throw very little light on the nature of the terrestrial vegetation" (*Seward, 1941, p.100*). This shows that the migration of plants, together with that of animals, towards land started most probably in Ordovician or, if earlier still, in Cambrian times. The microfossils recovered show all the signs of confirmed land plants, *i.e.*, the presence of wood cells and cuticle. This clearly indicates that the plants to which these fragments belonged must have existed later than the periods in which migration towards land started.

The oldest known vascular plants are primitive Pteridophyta from the Silurian of Victoria (*Lang and Cookson 1935*). On present evidence the occurrence of any vascular tissue indicates an age later than the Silurian. Well-formed large bordered pits such as those shown by many of the pieces of wood here figured (*e.g.* Text-figs. 13, 17, 27) are a much later development, and small simple pits of the type shown in text-figures 19 and 26 are an indication of Angiosperms, a group which evolved not earlier than the Middle Mesozoic (*Stokes, 1912*). The presence of these advanced characters in the microfossils from these rock samples thus affords decisive evidence in favour of a post-Cambrian age for the Saline Series.

I am greatly indebted to Professor B. Sahni, F.R.S. who kindly entrusted to me this investigation on cores originally sent to him, and for the indispensable guidance given to me during the course of the work.

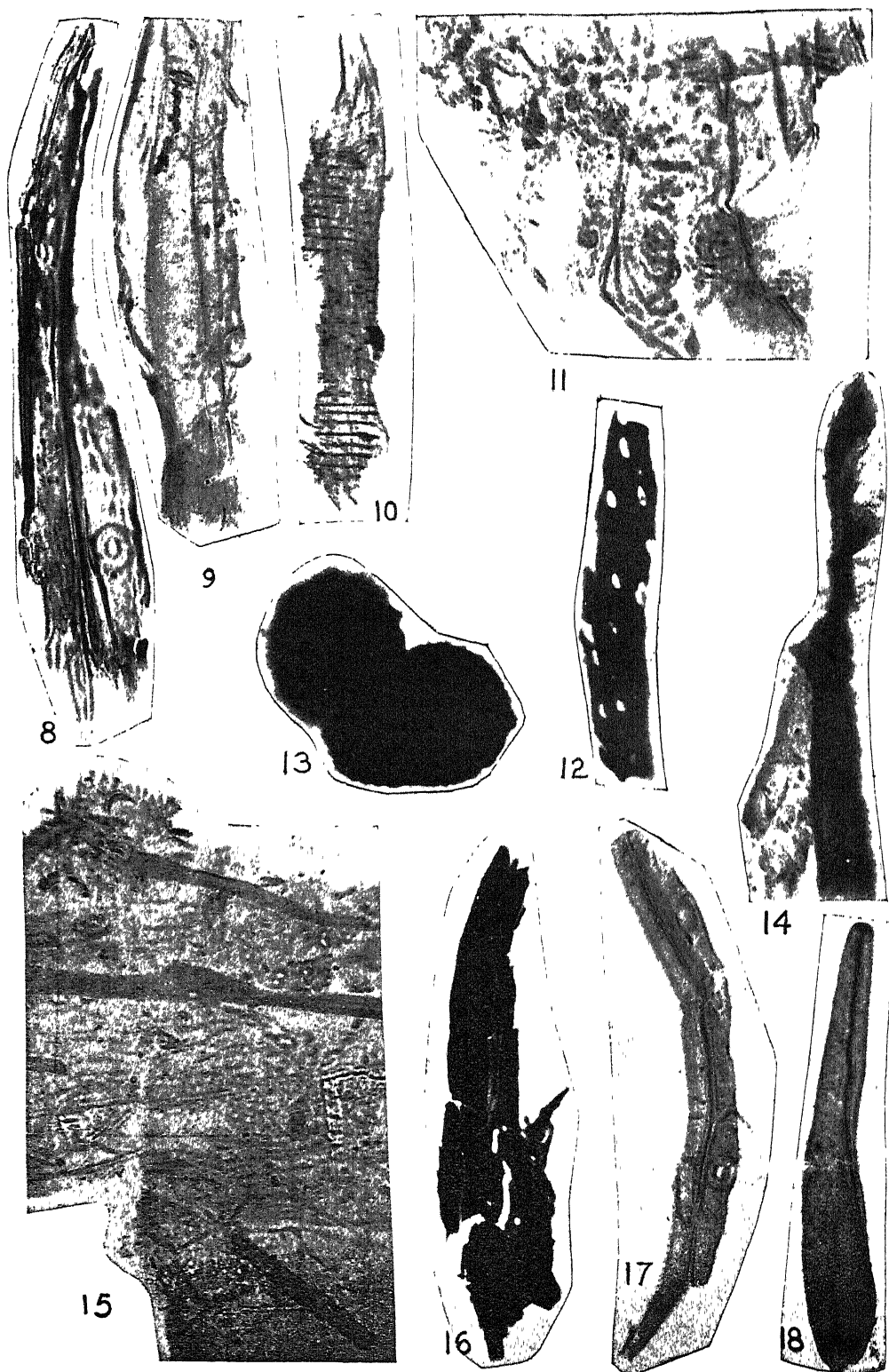
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R. N. L. photo.

Core of Salt-and-Marl (SRE 34),
Near Bhandar Kas.



R. N. L. photo.

Core-samples, Mayo Mine, Khewra.

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EXPLANATION OF PLATES.

Plate 1.

Microfossils from a core of Salt-and-Marl (S.R.E. 34) from an exploratory drift north of the Bhandar Kas, Khewra. Coll: E. R. Gee and party.

- Fig. 1. A gymnosperm tracheid (x126).
- Fig. 2. A portion of the same (x 675).
- Figs. 3-5 Pieces of wood, (3, x 405; 4, x 675; 5, x 650).
- Fig. 6. A piece of carbonised wood (x 510).
- Fig. 7. A piece of grass cuticle (x 1000).

Plate 2.

Microfossils from rock samples from a boring below the South Pharwala Section of the Mayo Salt Mine. Coll: B. S. Lamba.

- Fig. 8-12. Pieces of wood (8, x 400; 9, x 330; 10, x 88.5; 11, x 680; 12, x 1000). Fig. 11 is a portion of the piece in Fig. 10 magnified to show the bordered pits.
- Fig. 13. Fungal spores (x 1000).
- Fig. 14. A piece of cuticle overlaid by a piece of wood (x 350).
- Fig. 15. A piece of cuticle with 2 sinuous-walled cells (x 345).
- Fig. 16,17. Pieces of wood (16, x 560; 17, x 330).
- Fig. 18. A club-shaped structure containing a row of 'beads' (x 714).

EVIDENCE FOR EOCENE AGE OF SALINE FORMATION BENEATH SALT RANGE THRUST.

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ABSTRACT.

The gypseous and shaley beds just below the "Purple Sandstone" in the Khewra ravine are shown by their relations to be part of the "Saline formation". They contain carbonaceous layers and plant remains originally deposited with the sediments, among which leaf traces from within indurated beds were definitely identified as dicotyledonous, and therefore evidence that the formation is younger than the overlying Paleozoic. Additional lines of evidence point to an Eocene age of the Saline formation, and to the important part that thrusts have played in the Salt Range. The conclusion is that the Range represents thrusting of various horizons of the Paleozoic upon a saline facies of the Eocene, as well as upon later formations, and that the dislocations took place mainly in two epochs,—one post-Middle Siwalik and the other early Pleistocene.

INTRODUCTION.

A paper published by me (1927) cited various evidence in support of the conclusion that the Saline formation* of the Punjab is of Eocene age, and that the mass of the Paleozoic and later beds forming the Salt Range lies in a thrust relation upon it. Of this evidence the most definite was that of dicotyledonous leaf remains in the portion of the Saline formation immediately underlying the Cambrian. According to Mr. E. R. Gee (1944) this evidence was discarded by reason of uncertainty on the part of the Geological Survey of India as to the organic nature of the markings, and by reason of his failure on further search near the locality to find any recognizable fossil; as well as owing to the discovery by him elsewhere of stratigraphic features leading him to the conclusion that the formation is Cambrian or pre-Cambrian in age. I am indebted to Professor Sahni for sending me a copy of the papers presented at the 1944 symposium, and he has kindly invited my comments.

*The term "Saline formation" is employed here instead of "Saline Series" because of doubt whether this formation has the scope of a "series" in the technical meaning which attaches to the word in the minds of many geologists. The formation so designated is the whole body of beds of the general saline and gypseous type, and of presumed stratigraphic unity, having its typical occurrence along the base of the Salt Range; exclusive of later superimposed and extraneous deposits that have locally become attached by saline, calcareous and other forms of agglutination. In accordance with common usage the expression "salt marls" is occasionally employed interchangeably.

In view of the above, and the conclusion reached by various other geologists that the formation is Cambrian or older, as well as in view of the various hypotheses that have been advanced by them in an attempt to explain away the evidence for a Tertiary age, the following comments are offered regarding the strata in which I collected my specimens, and with respect to some other aspects of the problem.

PLANT-BEARING STRATA OF KHEWRA RAVINE.

The particular questions requiring consideration are—(a) whether the beds are definitely part of the Saline formation; (b) whether they contain plant material; (c) whether there is any possibility of this material having been later introduced; and (d) whether the fossils are diagnostic of a post-Palaeozoic age.

The zone in question comprises a thickness of about 20 meters of strata forming the portion of the "salt marls" immediately below the highly brecciated, lower, shaley portion of the "Purple Sandstone" formation. (The "Purple Sandstone", although possibly pre-Cambrian, seems to be with little question Cambrian in age by reason of its close lithologic similarity and relation to the "Neobolus beds" that overlie. For this reason as well as for the sake of brevity it is here referred to as Cambrian). The beds of the Saline formation are considerably broken, and at the contact with the overlying Cambrian they show the effects of squeezing and slickensiding, but the formational dip is northward beneath the north-ward-dipping Palaeozoic, from which this zone (and the Saline formation as a whole) is marked off in sharp contrast.

The zone is composed of laminated dolomitic, siliceous, carbonaceous, shaley, sandy and gypseous layers, interbedded with somewhat thicker beds of gypsum, and grading down into the main mass of the "salt marls". Some of the layers weather into white papery laminae, interlaminated with gypsum. The sedimentary types are such as characterize the less salty members of the Saline formation as a whole. But this zone (which by reason of its position is inferred to represent the upper portion of the formation) is more thinly and regularly stratified and less dominantly gypseous and saline than the bulk of the formation. The beds may be considered without question as originally a deposit of muddy and gritty, calcareous sediments, which have become in part altered into siliceous dolomitic replacement products.

The thin and lenticular "Khewra trap" is intimately included in this zone and generally completely enclosed within it, but locally comes into direct contact with the base of the Cambrian, although nowhere passing into the

Cambrian or known to occur in any portion of the geologic column other than the Saline formation (with the exception of somewhat similar occurrences in beds ascribed to the Eocene elsewhere in Northwestern India.) The trap is either contemporaneous with the zone in which it occurs or else a later intrusion. It may be noted in passing that the combustible carbonaceous layers which occur close to the trap do not show signs of burning, indicating that little heat was transmitted from this igneous rock at the time of its occupation of a position within these beds.

The relations satisfactorily demonstrate that the zone is a phase of the Saline formation. A hypothesis that it might represent some late detrital or alluvial deposit mechanically mingled or otherwise confused with the formation is excluded by the relations described, as well as by the character of the beds and stratification and the absence of any fragments or pebbles derived from the Nummulitic limestone or other strata of the Salt Range escarpment.

Moreover, any suggestion, such as has been put forward, that late plant material could have been introduced into the body of these beds through a process of solution or mechanical mixing is fanciful, in view of the absence of salt in this portion of the formation, the indurated character of the strata, and the evidence that the plant remains were both large and small (not merely microscopic) and were interstratified with the sediments when these were laid down.

The portions of the strata that are best exposed are described in my field notes of 1925 as beautifully laminated layers showing every gradation between the sedimentary types above mentioned and containing numerous thin laminae of carbonaceous material occurring mainly as partings and coatings between bedding planes. Some of these are interlaminated with hard, brittle calcareous and semi-flinty layers containing cherty lenses. The carbonaceous laminae occur both above and below the horizon of the "Khewra trap." Some of the siliceous ledges are full of small cavities that look as if they represent the space once occupied by carbonized plant fragments. In places the semi-siliceous, dolomitic limestone beds contain flat, black plant traces, in which, however, the leaf or plant structure has in general been all but obliterated by the alteration that the beds have undergone. It was in a bed such as this that I found leaf traces, on the left side of the Khewra ravine at a horizon several meters below that of the trap. Unfortunately the specimens which I dug out of the rock were packed away somewhere many years ago and cannot now be found and submitted to Dr. Sahni for microscopic study.

In addition to the carbonaceous laminae and traces above mentioned there occurs at a horizon about two meters below the trap a bed some 12 centimeters thick of brown, dry, leathery, but also brittle, material which will burn when ignited. No analysis was made to determine whether this is a lignite or an oil-shale, which latter it resembles. It is somewhat lenticular, splits into cardboard-like layers along wavy bedding planes, and contains pockets of siliceous sedimentary material. The character of this bed is clearly indicative of an origin as a sedimentary deposit of organic matter mingled with clastic sediments.

Reference may be made to the quotation from Dr. Ralph W. Chaney in my paper of 1927, wherein he reported fossil dicotyledonous leaves in the material which I submitted to him from the zone and locality above mentioned. I have informed him of the current debate on the subject and he writes as follows under date of November 8, 1945:

"Regarding the fossil material which you sent me in 1927, I may say that I examined it at that time with care. One specimen showed a considerable part of a small leaf which resembled a fossil species of oak common in the middle Tertiary of Western America. The fossil is related to a modern oak now living in Central and Southern China. The margin and nervation of this specimen were sufficiently well preserved to show beyond question that it represents a dicotyledonous leaf. Since the leaf was of relatively modern type, it was my opinion when I studied this specimen that it came from rocks younger than Cretaceous in which fossil leaves have a more archaic aspect. I still believe that the age of the deposits in which this fossil material was found is not older than Cretaceous and is probably Tertiary."

AFFINITY OF SALINE FORMATION TO PHASES OF EOCENE.

The view has been advanced by some that a prime reason for disbelieving in a Tertiary age of the "salt marks" is the lack of knowledge of such a formation in the Eocene or other Tertiary series outcropping only a few miles away on the north limb of the Salt Range, and elsewhere in the Punjab. This argument is weakened by the actual presence of saline beds in the Nummulitic on the top of the Range and by the following points that deserve mention.

1. Formations of the type of the Saline formation are peculiarly subject to lenticularity and to gradation laterally into other sediments as a result of

ocal variations in the basins of deposition. For example, in Western Algeria Miocene gypsum deposits (Mellah stage), which incidentally are characterized by abundant carbon specks and other plant traces, grade laterally into fossiliferous marine limestone on the north flank of the Beni Chougrane Range and elsewhere (*Anderson*, 1936). In the Red Sea "graber" area of Egypt it has been noted in numerous wells drilled in the Mio-Pliocene Series that stratified masses of salt, anhydrite, etc. of great thickness give place laterally in short distances to other sedimentary types. Such examples and many additional ones that could be cited help to support the observation made by Gee, Heron and others of gradation of a thick body of typical "salt marls" into Nummulitic limestone on top of the Salt Range southeast of Kalabagh (*Fermor*, 1935).

2. The "salt marl" facies southeast of Kalabagh is not the only occurrence of such deposits in the upper limb of the Salt Range. In supplement to what has been said with respect to these occurrences by Wyñne, Pascoe and others, I may quote the observation made in 1924 by Mr. D. Dale Condit, then a colleague in the work of the Whitehall Petroleum Corp., Ltd., to the effect that at Kallar Kahar there occurs a body of "gypsum and salty red clay several hundred feet thick apparently resting on the Nummulitic limestone along an extent of about half a mile, at each end of which Kamliar beds occupy their usual position in contact with the limestone."

3. The thickness and character of members of the Nummulitic series in the Punjab, both north and south of the Potwar Plateau, are variable from place to place, this variability being most readily observable in its less fossiliferous and softer members, where the original character is less obscured by induration into limestone. They are characterized by such features, among others, as clay shales, foraminiferal marls, oyster beds, gypsum beds up to many feet thick, lignitic deposits, sandstones both thick and thin and a diversification of grayish, whitish, greenish and purplish colours. These strata appear to represent deposits in relatively shallow, partly-enclosed basins, and contain sedimentary types showing kinship with those forming the better stratified portions of the Saline formation. Thus it is entirely in keeping with the character of the Nummulitic series to conceive of parts of it grading into evaporation-basin phases of the "salt marl" type.

4. If we are to rely upon the evidence of southward thrusting in the Salt Range, which evidence is in part quite independent of the thesis of a post-Paleozoic age of the Saline formation and is brought out in several superimposed faulted segments, it follows that the portions of the Nummulitic series as now

exposed on the summit of the Range, in present proximity to the Saline formation beneath the Range, were deposited farther north than their present position. Thus two separate portions of the basin of deposition are represented, between which a change of sedimentary facies might readily have taken place.

INADEQUACY OF INDICATIONS AS TO CAMBRIAN OR EARLIER AGE OF SALINE FORMATION.

Aside from the position of the Punjab Saline formation (in its main outcrops) beneath either the Cambrian or the Carboniferous, the indication of a Paleozoic or older age for it, when boiled down to the essential direct evidence, is the evidence presented by Gee of the existence, at a few points, of what appears to be a depositional unconformity of the Carboniferous conglomerate upon it. We are indebted to Mr. Gee for his extensive observations, and objective approach to the problem of the age of the Saline formation, with respect to which anyone who has studied the Salt Range will recognize the manifold puzzling features and seemingly contradictory clues. But with due deference to Gee's opinion and his fuller knowledge of the region, it may be pointed out that lithologic field indications of unconformities are often very deceptive, and the statement of the evidence as so far presented does not make it appear conclusive. Among the questions that come to mind are the following:

- (a) Whether the uppermost beds beneath the conglomerate, which are referred to the Saline formation at the points of seeming unconformity, can be definitely correlated with that formation; and similarly in the case of correlation of the conglomerate with the "Talchir." While these correlations are presumably correct there is possibility of confusion in beds of these types and in a section so badly faulted.
- (b) Whether the inclusions in the conglomerate which are supposedly derived from the Saline formation can be conclusively identified as so derived, instead of coming from the "salt pseudomorph" beds or other Paleozoic formation.
- (c) Whether these inclusions in the conglomerate, as well as the boulders of the latter reported as partly imbedded in the uppermost dolomitic layer below, may not represent re-consolidation seemingly in the body of the strata of inclusions that really represent splintering along a fault. The relative thinness of the Saline formation at the points in question suggests that it occurs as a slice of the formation along a plane of faulting.

DEFORMATIONAL HISTORY.

Some of the complexity of the problems relating to the Saline formation is due to the pronounced thrust faulting that has played a profound, if not dominant, part in the Salt Range in bringing the formations into their present position. Such structure is shown, for instance, by the overthrust of the Paleozoic upon various horizons of early and late Siwalik at the eastern end of the Salt Range, northwest and north of Jalalpur. Furthermore, it may be noted that in portions of that region the only trace of the Saline formation is in the form of a gypsaceous gouge along faults; and the inference may be drawn that in various other portions of the Range bands of "salt marls" following for long distances the boundaries between outcrops of other formations are in the nature of slivers and brecciated masses carried along fault planes and acting as lubricating media for such faults. The usually brecciated nature of the contact zones between the Saline formation and the Paleozoic formations that lie upon it is significant. And it is to be noted that locally a consolidation and cementation of the brecciated zone has caused an appearance of continuity from one formation to the other. Another complicating element is the fact that the present structure represents not merely one or two episodes of disturbance but was the result either of continuing deformation subsequent to the Eocene or of at least three major epochs of orogeny, each of which superimposed new stresses upon the result of previous deformation.

The structural evolution within the Nimadric basin of deposition was previously discussed by me (*Anderson, 1927*) as deduced from the sedimentary record and other observed facts. Deformation subsequent to the Nummulitic appears to have been more or less continuous, and cumulative in its results, and it is probably a distortion of truth to speak of definite epochs of deformation as contrasted with depositional ones. However, as a means of bringing the results into focus we may conceive of them as concentrated mainly during the following three diastrophic epochs:

- (1) The epoch of upheaval between the Nummulitic and the Nimadric, of which evidence is seen in the termination of marine deposition and the structural unconformity between the two series, including the erosional wearing down of the Nummulitic and its entire removal in some areas prior to the times at which various Nimadric horizons overlapped in different places.
- (2) The epoch of rejuvenation, and probably local folding and faulting, which initiated and continued to nourish the Upper Siwalik; during

which the Nummulitic limestone became exposed in high ground tributary to the area of Siwalik deposition near the present Salt Range. Such exposure is proven by the abundant boulders (up to 30 centimeters thick) of Nummulitic limestone in the thick formation of late Siwalik conglomerate at the south-eastern foot of the Salt Range. This formation stands virtually on end, and is 600 or more meters thick as I recall. In addition to the uplift and exposures of the Nummulitic, the underlying formations down to the Cambrian were probably exposed at that time judging by other boulders, including poorly-rounded blocks up to 40 centimeters or more in diameter of micaceous purple sandstone identical in appearance with that of the Cambrian.

- (3) The post-Siwalik revolution, inferred as mainly taking place during the first half of the Pleistocene, which had such profound effects in folding and faulting the Upper Siwalik, as well as the earlier stages which had experienced previous deformation of at least a local nature; in causing overthrusts such as already mentioned of the Paleozoic and later strata upon the highly tilted Siwalik; and in general in raising the mountain and hill masses to their modern form and position.

The region occupied by the mass which now forms the Salt Range would appear to have been endowed with a positive tendency from a time at least as far back as the close of the Nummulitic. This is demonstrated by the exposure and partial erosion of the Nummulitic (and locally older rocks) for a time after that period, and by a lesser amount of subsidence during the Nimadric stages than prevailed farther north. The early Nimadric orogeny may have initiated fracturing and a tendency toward one or more thrusts in or beneath the mass now forming the Range, but judging by the evidences of moderate relief during that orogenic epoch, and by the fact that the region subsided to accommodate the deposition upon it of at least the Lower and Middle Siwalik, the inference is drawn that the early deformation was more in the nature of gentle arching, and that the main dislocations of the mass did not occur until the post-middle Siwalik and post-upper Siwalik epochs mentioned above.

CONCLUSION.

In the attempt at an unbiased view I can find no basis for discounting the fossil evidence of a post-Paleozoic age of the Saline formation. Once this evidence is accepted, the numerous additional indications clearly point to its

correlation with a portion of the Nummulitic. Obviously, a post-Paleozoic age implies a thrust relationship. But quite aside from the fossil evidence there are structural proofs that thrusts of magnitude occurred in the Salt Range during at least the post-Siwalik revolution and in view of these, including evidence of overthrusting of the Cambrian upon the highly tilted Siwalik, there appears no reason to doubt its having been thrust over the Saline formation as well.

The conclusion reached is that the fundamental structure of the Salt Range consists of a great southward thrust of low angle, and a composite of subsidiary thrusts, upon a saline and gypseous formation of Eocene age. It is believed that such structure began to bring about exposure of the Nummulitic and older rocks at the close of the epoch represented by the Middle Siwalik and reached intensified development in the early Pleistocene. Contemporaneously with the growth of this structural feature and the erosional wearing back of the resulting escarpment during the Upper Siwalik epoch, the region south of at least the eastern portion of the rising mass went on subsiding and receiving a thick accumulation of conglomerate during that epoch. Subsidence and deposition likewise continued to the north and east. The main culmination of the movements thereafter occurred during the strong post-Siwalik deformation, accompanied or followed by the compressional warping of the planes of thrust and of the formations above and below them, thereby adding to the semblance of structural uniformity between these formations.

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FURTHER NOTES ON THE AGE OF THE SALT RANGE SALINE SERIES*

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In a previous note (Pinfold 1944) the resemblances and differences between the Salt Range Saline series and the Lower Chharat (Eocene) beds of northern sections were described, and it was pointed out that the main difference is the absence of fresh-water molluscan and vertebrate fossils in the Saline Series, whereas they are common in all the outcrops of the Lower Chharat. It should be emphasised that the Lower Chharat beds are the only formation in the Eocene or the Tertiary sequence which bear any resemblance to the Salt Range salt marls; it is generally agreed that if the Salt Range Saline Series is of Tertiary age it must be the southern equivalent of the Lower Chharat stage. Pascoe (1920) went so far as to suggest that the Purple Sandstones of the Salt Range were the equivalent of sandstone bands which are frequently present in the Lower Chharat. The Lower Chharat sandstones, however, invariably contain bone fragments, whereas no similar remains have been reported in the Purple Sandstones. Gee has demonstrated during recent excursions in the field that there is usually a normal stratigraphic contact between the Purple Sandstones and the overlying Neobolus beds, the junction being marked by a thin gravel bed.

Cotter (1933) was of the opinion that the Saline Series was Ranikot (Lower Eocene) in age, but he, unfortunately, was under some misapprehension regarding the evidence from the Salt Range, and also about the Eocene succession further north. At that time it was thought that the foraminifera found in the Salt Marl were *in situ* and that they proved the Ranikot age of the deposit. Cotter believed also that other marine Ranikot beds were absent from the Salt Range and the north-west Punjab. In all these points Cotter has since been shown to have been mistaken. Marine Ranikot limestones and shales are present in typical development throughout the Salt Range and in the Kala Chitta and Hazara hills to the north; most of Cotter's 'Hill Limestone' is highly

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fossiliferous and contains all the characteristic Ranikot forms. No bed resembling the Saline Series occurs in normal succession in the Ranikot of either area. The foraminifera thought to be in the Saline Series were shown quite clearly by P. Evans and the writer to occur in stream gravels which had become incorporated in the marls by erosion and slipping.

EVIDENCE FROM DEEP WELLS.

Cotter was one of the few who have had the courage to delineate the supposed *nappe* structure of the Salt Range in diagrammatic form (*ibid*, Plate 18). His section shows a horizontal sheet stretching for over one hundred miles to include the Kala Chitta hills, but makes no attempt to indicate the roots and origin of this great *nappe*. The glide plane along which the movement was presumed to have occurred was in the salt marl which Cotter believed was at the base of the Eocene; the occurrence of the marl at other horizons Cotter explained as being due to intrusion of the marl along the plane of the main movement.

Since Cotter produced his memoir a deep well has been drilled as a test for oil near Jhatla ($32^{\circ}49'$; $72^{\circ}23'$), twenty miles north of the main scarp of the Salt Range. According to Cotter's diagrammatic section, this well should have drilled through the thick blanket of Murree/Siwalik sandstones and shales, and then through the Eocene limestones and shales, and encountered the salt marl immediately below. It would then have passed through the glide-plane and entered the rocks of the basement complex. In the actual result, the well entered the Eocene at 5911 feet and drilled through the normal Eocene sequence—Bhadrar Beds, Sakesar Limestone, Nammal stage, Ranikot limestones, shales, and sandstone—and then passed directly into Middle Products Limestone. It was later carried through the Lavender Clays into the Speckled Sandstone and was stopped in this formation at a depth of 7957 feet. Two points should be noted:

- (1) At this important key location, no formation resembling the salt marl occurs in the Eocene or at any other of the horizons penetrated.
- (2) The sequence of rocks in and below the Eocene is that of the Salt Range to the south of the well location; it is not that of more northerly sections, for in the Kala Chitta and Margala hills there is a considerable development of Kioto Limestone, believed to be Triassic, and the Productus Limestone and lower formations are not represented.

No trace of any important faulting was observed in the cores taken from the well, and the dips throughout were low. That the rocks drilled through were not of the northern facies but those normal to the adjacent portions of the Salt Range indicates that they cannot have formed part of a great nappe thrust over considerable distances from north to south. On the other hand, the well results indicate a quite undisturbed and straightforward structural connection with the Salt Range outcrops twenty miles to the south.

It may seem superfluous now to attack Cotter's interpretation, but the evidence, cited for the first time in the preceding paragraphs, has a direct bearing on any theory of Salt Range structure which involves large scale earth movements of alpine type.

THE EASTERN END OF THE RANGE.

Professor Sahni (1944) mentions the appearance of the Salt Range on a geological map and suggests that "...it looks almost as if one could cut out this enormous nappe and thrust it back into its original northerly position". If we had only the southern and western arms of the Salt Range as evidence, this might have been a difficult point to refute; for in these areas the relations of the structure to the adjacent plains is entirely obscured by alluvium. At the eastern end of the Range, however, the geology is more fully exposed and the Salt Range can be seen to finger out in a series of faulted but open anticlinal folds. From the plains northwestwards these folds are: the Pabbi Hills, a broad dome in Upper Siwalik rocks lying to the south-east of the Jhelum River; the Rohtas anticline which continues the Mt. Tilla structure to the north-east; the Mahesian anticline; and the Bakrala ridge, a sharply folded anticlinal, overthrust to the south, and exposing at its core a thin representative of the Eocene resting on Cambrian. All these fold axes strike approximately east 30° north, but a short distance further to the north-east the strike swings round in a smooth arc to east 40° south, the regional strike of the Poonch hills. The eastern border of the supposed Salt Range nappe should underlie the Siwalik blanket in this area about on the line of the Jhelum River. If this had been the case one would have expected some reflection of it produced by the much more violent earth movements which occurred in late Siwalik times.

One of the most difficult points connected with the nappe hypothesis, well illustrated in the magnificent sections at the eastern end of the range, is the absence of any discordance in dip between the basal beds of the Murree/Siwalik and older rocks. The nappe is believed to have been formed in post-Eocene pre-Siwalik times, yet there is no trace of mountain building move-

ments in this part of India in this period. In the scarps east of Jalalpur visited during Mr. Gee's recent excursion, Lower Siwalik deposits of Miocene age can be seen resting directly on Cambrian Neobolus Shales over many miles of continuous exposure without any apparent discordance of dip. Similar sections are seen in the Tilla, Diljaba, and Bakralla ridges further east, the Cambrian beds being sometimes overlain by thin representatives of the Eocene. Similar parallelism of dip is to be seen throughout the dip slopes on the northern flanks of the main range, and continues through the Potwar oil-fields to the northern hills. The absence of post-Eocene pre-Siwalik folding anywhere in the region is strong evidence that no large scale earth movements occurred in this period.

STRUCTURE IN FRONT OF THE RANGE.

It is only at the eastern end of the Range, from the neighbourhood of Jalalpur eastwards, that the relation of the Salt Range scarp to the plains structure is exposed, all the remaining country at the foot of the scarp being obscured by alluvium. A short distance west of Jalalpur the salt marl, and Cambrian can be seen resting against and overthrust upon Siwalik rocks dipping steeply southwards. The whole of the faulting and overthrusting appears to have taken place since the Siwalik rocks were laid down. This is indicated also by many sections in other parts of the Salt Range. At Amb and near Chidderu, for example, blocks of Siwalik rocks have been let down by faulting into the very heart of the range, and have undergone equally severe disturbance as the older formations.

It seems highly probable that Siwalik rocks underlie the alluvium along most of the southern foot of the Salt Range scarp. At Khewra, twenty miles west of Jalalpur, Bhag Singh Lamba has recently recorded the occurrence of nummulitic limestone beneath the salt marl and gypsum in two bore holes put down at the foot of the salt mine hill. It seems probable that the limestone is *in situ* and forms part of the down thrown side of the main fault in structural continuation with the Siwalik outcrops west of Jalalpur, mentioned above. The limestones have been over-ridden by the salt marl due to overthrusting, slippage, or direct flow. This interesting occurrence may be regarded by some as evidence for the Eocene age of the salt marls but this cannot be accepted. If the bore holes had been located in a similar position on the salt marl west of Jalalpur, the holes would have passed from salt marl into Siwalik rocks, but this, obviously, does not indicate that the marls are therefore of Siwalik age; the two cases would be strictly analogous. It is hoped that the species of foraminifera present in the cores will be determined; we now have a very thorough knowledge of the Eocene fossils and should be able to assign quite small samples of fossiliferous limestone to their correct places in the Eocene sequence.

FRACTURED BOULDERS.

The fractured boulders of the Talchir tillite have again been quoted as evidence of considerable earth movements. Exactly similar fractures occur in late Siwalik boulder beds where no extensive earth movement can have occurred. In both cases the broken portions of individual boulders remain in close juxtaposition and the extent of differential movement is slight; there is no suggestion of a fault breccia.

THE SALT MARL OCCURRENCES NEAR KALLAR KAHAR.

It has recently been claimed that the salt marl at Kallar Khar on the north side of the range is interbedded normally with the Eocene limestones, and this locality was therefore included in the itinerary of Mr. Gee's recent excursion. This outcrop of marl was shown to occur in a narrow, somewhat sinuous fault zone, the marl being seen to be in contact on the northern side with all members of the succession from Kamliar beds down to the Lavender Clays. Kamliar beds were also involved in the faulting and small fragmentary outcrops were seen on both north and south sides of the marls. A possible explanation is that the salt marl has been forced up as an intrusive mass along a tensional fracture zone. A similar dyke-like mass of salt marl, 'intrusive' into Siwalik rocks, connects the two scarp faults east and west of Jalalpur.

That the salt marl does not form any part of the Eocene succession in the Kallar Kahar area was clearly seen in the scarp sections to the north of the fault zone which expose the whole sequence from kamliar through Laki and Ranikot limestones down to the Lavender Clays of the Carboniferous. No beds resembling the salt marls occur in this or in any of the near-by sections within the Eocene.

THE SALT RANGE AS A BLOCK FAULT STRUCTURE.

In 1918 I emphasised the view that the Salt Range is an example of block fault structure (*Pinfold* 1918) and during several more recent visits I have seen no cause to modify this opinion: The Salt Range is, for the most part, the scarp edge to the Potwar plateau. The region for some miles to the north of it, more especially in the west is a region of very low dips; the folding becomes gradually more intense northwards and north-eastwards where the regional structure merges into the foot hill zone of the Himalaya. The southwards progression of the Himalayan folding appears to have ceased before the Salt Range area became seriously involved. In the Salt Range scarp and in the plateau region adjacent to it, faulting is much more prominent than folding, and what folding does occur appears to have been determined by the faults.

This is indicated by rapid changes in the strike, well seen at the eastern end of the range. These changes in strike are frequently accompanied by a complete reversal of throw and overthrusting of the associated faults. Thus, from Jalalpur eastwards, the succession of structures is as follows:

	Strike.	Dowthrow
Ridge west of Jalalpur	E30°S	SSW
Chambal Ridge	N—S	W
Mt. Tilla	E30°N	SSE

These three ridges form the eastern end of the main range. A parallel inner fault line runs north-eastwards through the Karangli, Diljaba, and Bakrala ridges and, although the strike along this line is more constant, there is again a complete reversal of throw between the Diljaba and Makrala structures; in the former the dowthrow is to the north-west, in the latter it is to the south-east.

These reversals of throw appear to be hinge movements of a type quite foreign to the northern folded regions. They can be explained as being due to differential vertical movement under tension.

There is a large number of smaller faults, some of which are approximately parallel to the general strike, and others which radiate from points in the main scarp like subsidiary cracks in a fractured sheet of plate glass. Some of these minor faults can be seen in the angle between the Jalalpur and Chambal ridges.

The sharp bend which occurs at the junction of the southern and western arms of the range may well be due to a sudden change in the direction of the faulting similar to that which occurs at Jalalpur.

It is probable that the greater part of the faulting occurred prior to the inception of the folding. During the later compression associated with the main Himalayan upheaval the faults acted either as planes of weakness or as barriers, and subsidiary folds resulted close to and parallel with the faults. At the same time there would be a tendency for the fault planes to be overturned and to be overthrust towards the dowthrow. This action would be most pronounced near the surface and would decrease with depth.

Much of the minor faulting is due to direct slips down the scarps, often with subsequent over-riding, or to collapses caused by solution and flow in the salt marls and gypsum. Other overthrusts and overfolds may be explained by the sliding and buckling of limestone dip slopes under their own weight. The local complications below the scarps and in the deep gorges are caused by the outward flow of the incompetent salt marl and gypsum beds under the weight, of the high rock columns in the adjacent scarps. This type of local structure has frequently been observed in the excavations for dam foundations; similar occurrences on a smaller scale have recently been described in the ironstone fields of Northamptonshire (*Hollingsworth, Taylor and Kellaway 1944*).

There are good reasons, therefore, for considering the structure of the Salt Range as being different from the imbrication and overfolding of the Himalayan foothills. The Salt Range structure has much more in common with that of the Khasi Jaintia Hills and the Shillong plateau which occupy an exactly similar position across the outer portion of the syntaxis between the eastern Himalaya and the Assam hills. In this case the block structure is more readily discernible, for the scarp has suffered less severely from erosion and there are fewer local complications; slips and collapses occur to a much less extent owing to the absence of incompetent beds such as occur at the base of the Salt Range scarp.

CONCLUSION

Several of the contributors to the Poona symposium regarded the problem of the Salt Range Saline Series as being "settled" by some part or other of the evidence. This attitude is to be deprecated, for until definite fossil evidence acceptable to all is found, or until the geological arguments find equally general acceptance, there must remain differences of opinion. This is by no means to be regretted; for such differences should act as a spur to further investigation and continued interest. As it stands at present the problem is one of considerable difficulty and, although the geological evidence seems to some of us incontrovertible, we would not claim that the last word has been spoken until some satisfactory explanation of Professor Sahni's results is found.

The Academy owes a considerable debt to Mr. Gee who has given so generously of his time and knowledge in conducting the two field excursions. It was fortunate that Professor Sahni was able to attend the second excursion, and I have no doubt that the discussions we held in the field will help him to appreciate the solid grounds we have for holding to our present opinion until more definite evidence is produced to the contrary.

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MICROFOSSILS FROM THE SALINE SERIES IN THE SALT RANGE, PUNJAB.

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(With 104 figures in the text and one chart)

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ABSTRACT.

In the present paper are incorporated the data obtained by an extensive microfossil examination of various rock types from the Saline Series in the Salt Range.

The Saline Series is mainly composed of four kinds of rocks: (1) Rock-salt and Marl, (2) Dolomites, (3) Oil Shales and (4) Gypsum. Of these only the first three have been analysed by the author for microfossils. Gypsum was not tried because it is only slightly soluble in concentrated HCl and that too with difficulty.

Seventeen samples of saline rocks, eight samples of dolomites, one of dolomitic limestone and five samples of oil shales were analysed. The samples of dolomites and oil shales include some collected by the Salt Range Excursion party led by Mr. E. R. Gee in November, 1944, besides samples collected by Professor Sahni in October, 1943 and October, 1944. Only such pieces of rocks were examined as were free from pits or cracks; and all precautions were taken to avoid atmospheric contamination.

All the samples examined have yielded microfossils. The microfossils recovered belong to gymnosperms and such relatively young groups as the angiosperms and insects. There are several types of angiospermous and gymnospermous woods, of angiosperm cuticles and of spores. Most of the cuticles are typically like those of the grasses. A large number of other plant fragments *e.g.*, hairs, plant cells, fungi, membranes etc. have been obtained. Insect remains have been found in all the three main types of rock.

The nature of plant and animal microfossils thus obtained points definitely against a Cambrian age for the beds. On the contrary the fossil evidence, considered as a whole, very strongly supports a Tertiary age and this is consistent with the stratigraphical evidence put forward by several geologists.

INTRODUCTION.

Recent discussions on the age of the Saline Series in the Punjab have shown the importance of making a more thorough investigation of the microfossil content of these rocks. The fossil evidence affords ample proof that the series cannot be older than middle Mesozoic and some of the organic remains cannot be older than Tertiary. But those who uphold a Cambrian or pre-Cambrian age have, on the one hand objected that very few of the microfossils can be referred to a definite geological horizon, and on the other have claimed that there is no proof of their being indigenous to the rocks.

Professor Sahni therefore suggested that a more extensive search might lead to the discovery of fossils which can be definitely dated. An extensive analysis of the rocks was undertaken. The microfossils obtained are mostly too fragmentary to be of any use in specific determinations but some of them are well enough preserved to serve as valuable guides for dating the beds in which they occur.

The grass cuticles, angiosperm hairs, and the insect *Chironomus primitivus* clearly show that the Saline Series cannot be older than middle Mesozoic. Some of the stratigraphic geologists claim that the Series cannot be younger than Eocene and the fossil evidence is quite consistent with this view. The fossil evidence as a whole is overwhelmingly opposed to the Cambrian view.

ACKNOWLEDGMENTS.

The earlier part of this work was done jointly with Professor Sahni and it was originally intended to publish a joint paper but later, as Professor Sahni was unable to give much time to the laboratory work, the entire investigation was entrusted to me. I express my deep debt of gratitude to Professor Sahni for kindly entrusting this problem to me and for his constant guidance. I also thank him for the use of his personal library without which many of the references to the literature would not have been available.

LIST OF ROCK SPECIMENS EXAMINED WITH LOCALITIES.

I. (a). *Saline Rocks of Khewra.*

Sahni No. 1. Salt and Marl. *Loc.* Pharwala Seam, Chamber No. 17, 26 incline upperlevel, distance from entrance 4,150 ft. at Low Level Tunnel. Depth from surface 730 ft. Coll. B. Sahni and Party, 5-10-1943.

Phillips Nos. 1-7. Salt and Marl. *Loc.* Chamber No. 46, on the 43 incline 2nd sub-level north, surface height 660 ft., distance from mine mouth 6,200 ft. Coll. C. Phillips, 16-2-1944.

K₄. Salt and Marl. *Loc.* A band of Salt and Marl about 3'' thick on the eastern end of chamber 19, middle Pharwala, Mayo Salt Mine. Coll. B. Sahni and party 3-10-1943.

K₅. Salt and Marl. *Loc.* Pillar 47-48, 43 incline 2nd sub-level north within the Buggy Seam, Mayo Salt Mine. (*Sahni 1945, Photo. 2, the bands from where the samples were taken are marked, K₅, K₆ and K₇.*) Coll. B. Sahni and Party, 3-10-1943.

K_{6a}. Salt and Marl. *Loc.* as above. Coll. B. Sahni and party, 3-10-1943.

K₇. Salt and Marl. *Loc.* as above. Coll. B. Sahni and party, 3-10-1943.

I (b). *Saline Rocks of Warchha.*

Sahni No. 1. Salt and Marl. *Loc.* Kallar band interbedded with Rock-salt in a Tunnel of the Warchha Mine. Coll. B. Sahni and party, 14-10-1943.

Lamba No. 2. Salt and Marl. *Loc.* Top Marl in Chamber No. 20, New, Low Level Tunnel, about 1 furlong from entrance, elevation 980 ft., dip. 38° Coll. B. S. Lamba, 9-12-1943.

Lamba No. 3. Salt and Marl. *Loc.* Marl between top and 2nd seams; as above. Coll. B. S. Lamba, 9-12-1943.

II (a). *Dolomites of Warchha.*

S/21 I. Hard, compact, finely laminated grey or chocolate coloured dolomite. The rock smells feebly of oil even without heating; after heating the smell of oil is quite pronounced and a little smoke is given out. It cannot be ignited but glows in the flame; effervesces vigorously with cold 4% HCl. *Loc.* Confluence of the Jarhanwala and the Jansukh streams. Coll. B. Sahni and Party, 14-10-1943.

S/21 II. Dolomite. Physical properties as those of S/21 I, except that it is more compact, hard and dark in colour. *Loc.* as above. Coll. B. Sahni and party 14-10-1943.

S.R.E.40. Grey, compact, very finely laminated dolomite. Smells of oil even without heating, effervesces vigorously with cold 4% HCl. It resembles S/21 I in other physical properties. *Loc.* Confluence of the Jarhanwala and the Jansukh streams. Coll. E. R. Gee and party, Nov. 1944.

W₄. Hard, compact dolomite with white and dark bands. Does not effervesce with cold dil. HCl. Some part of it, however, dissolves in conc. HCl after a prolonged treatment. *Loc.* From an outcrop of contorted and shattered gypsum and dolomite rocks near the stream bed on the left bank of the main Warchha nala below the junction. Coll. B. Sahni and party, 5-10-1944.

W₇. Grey, compact, finely laminated rock, some of the rock pieces are pitted others are without them. Only pieces free from pits were analysed. Effervesces with 4% HCl, on heating gives out smell of oil and a little smoke. Thin flakes of mica are sometimes seen associated with the rock. *Loc.* Left bank of the Warchha nala just near the pillar supporting the fresh water pipe line. Coll. B. Sahni and party, 5-10-1944.

W₁₄. Grey banded rock with pits infilled with a black crystalline mineral which gets scratched with an iron needle. Only the banded portion of the rock was analysed, the infilled part was rejected. The rock is hard and compact and does not effervesce with cold dil. HCl. *Loc.* The main rock of the "oil shale" outcrop. (*Reed, Cotter and Lahiri* 1930, *Plate* 11, *Fig.* 1; also *Sahni* 1945, *Photo.* 5). Coll. B. Sahni and party, 5-10-1944.

W₁₅. Grey compact dolomitic rock, finely laminated. Some pieces are pitted, no smell of oil even after heating. Effervesces with cold 4% HCl. *Loc.* The main rock of the "oil shale" outcrop. (*Reed, Cotter and Lahiri* 1930, *plate* 11, *Fig.* 1; also *Sahni* 1945, *Photo.* 5). Coll. B. Sahni and party, 5-10-1944.

W.S.D. No. 7. Greyish soft rock, slightly saline in taste with small black specks visible at the surface. Effervesces vigorously with cold 4% HCl. *Loc.* Dolomitic band in the Saline Series, New Low Level Tunnel, at least 1,500 ft. from Tunnel mouth, Warchha Salt Mine. Coll. B. S. Lamba, July 1944.

II(b). *Dolomitic Limestone of Khewra.*

K.D.L.L. III. Grey, soft, dolomitic limestone, effervesces vigorously with cold 4% HCl. *Loc.* 1,335 ft. from mine mouth, New Low Level Tunnel, Mayo Salt Mine. Coll. B. S. Lamba, July 1944.

III(a). *Oil Shales of Warchha.*

S/20. Dark grey, or almost black, compact and finely laminated oil shale. Associated with the oil shale are small whitish glistening particles, probably mica flakes, which are easily scratched with an iron needle. The oil shale smells feebly of oil but if heated even with a match the smell of oil is copious; in a Bunsen burner flame the smell of oil is very much more pronounced and a large amount of bluish black smoke is given out. The oil shale when heated decrepitates and breaks up into small pieces; when strongly heated it burns for a short time with a slight smoky flame even after its removal from the flame. Dil. or Conc. HCl has no action but the rock gets macerated with KClO_3 and HNO_3 . *Loc.* Confluence of the Jarhanwala and the Jansukh streams, Lower part of the Saline Series. Coll. B. Sahni and party, 14 Oct. 1943.

S/20 I. Grey, compact, finely laminated oil shale. Smells of oil even without heating, after heating the smell is more pronounced. When heated decrepitates, gives out smoke and burns for a short time even when removed from the flame. Effervesces with cold 12% HCl. *Loc.* as above. Coll. B. Sahni and party, 14 Oct. 1943.

S/20 II. Oil shale. Physical properties as above except that it is more compact. *Loc.* as above. Coll. B. Sahni and party, 14 Oct. 1943.

S.R.E. 38. Very compact and finely laminated oil shale, dull black or dark grey in colour; like S/20. Smells of oil even without heating. HCl dil. or conc. hot or cold has no action. It is very similar to S/20 in its physical properties. *Loc.* Confluence of the Jarhanwala and Jansukh streams. Coll. E. R. Gee and party, Nov. 1944.

III(b). *Oil Shale of Makrach.*

S.R.E. 19. Very light finely laminated dark black oil shale with a shining lustre. The rock is soft and compact and gets easily scratched with an

iron needle. HCl dil. or conc. hot or cold has no action but the rock gets macerated with $KClO_3$ and HNO_3 . Burns with a smoky flame when heated in a burner and continues to do so for some time even after its removal from the flame. *Loc.* Upper Gypsum Stage of the Saline Series in the Nawabi Kas (Makrach). Coll. E. R. Gee and party, Nov. 1944.

DESCRIPTION

1. PLANT REMAINS.

Part I (A). MICROFOSSILS FROM THE SALINE ROCKS OF KHEWRA.

Sample: Sahni No. 1. (Salt and Marl but mostly Marl).

(a) A well preserved piece of cuticle of one of the Gramineae (Text-fig. 1). The epidermal cell walls are sinuous. The stomata are longitudinally aligned; they are 33.8μ long and 15.6μ wide. One short cell (*Prat* 1932, p. 126) is also seen; this is much smaller than the epidermal cells.

(b) A poorly preserved piece of wood (Text-figs. 2 & 3) with 8 circular, contiguous or separate bordered pits. At one end of the piece is a slight indication of a 3 or 4 cells high medullary ray.

(c) A piece of crushed wood (Text-fig. 4). Shows two, oval separate bordered pits.

(d) An epidermal hair of a plant, 150.8μ long and 15.6μ wide at the base. The hair gradually tapers from the base till at the apex it measures only 2.6μ . Beginning at the base and extending to beyond three-fourths of its length, mostly on one side, the hair is surrounded by a membranous cuticle-like structure. A little of this membrane is on the other side of the hair as well.

Sample: Sahni No. 1. (Salt almost free from Marl).

(a) A tissue composed of rectangular pitted cells (Text-fig. 6). Pits Simple, slightly oval uni-, bi- or triseriately arranged. The cell walls are thin.

(b) A poorly preserved piece of tissue which shows some silica cells only. The silica cells are 2 to 3μ long, and usually about as broad and abundantly distributed all over the surface of the tissue. They have various shapes; some are almost circular while a few are squarish. No stomata are preserved.

(c) A membranous structure (Text-fig. 7), which is only slightly stained. The presence of silica cells points that it is probably a monocot cuticle. No stomata are preserved. The silica cells are numerous and are either squarish or triangular in shape. The squarish ones measure from 5.2μ to 7.8μ both

in length and breadth. A few faint straight lines appear to run throughout the length of the cuticle; they probably represent the fibrous strands below the epidermal cells.

(d) A large well preserved stoma (Text-fig. 8) (Sahni 1944a, Fig. 7, p. 56), is associated and lies over a piece of tissue consisting of many tubular structures with very thick walls; they are 5 to 13μ in thickness. These tubes may probably be wood vessels, but no pits are visible. One side of the tissue is more deeply stained than the rest and is composed of well preserved woody elements which have scalariform thickenings.

The stoma is 101.4μ long and 27.2μ broad. The outline of the two guard cells is clear throughout except at the apices where it seems to have degenerated and broken irregularly. Each guard cell is about 12.2μ wide. The stomata aperture is slit like and about 2μ in width.

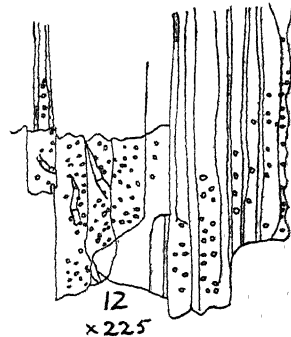
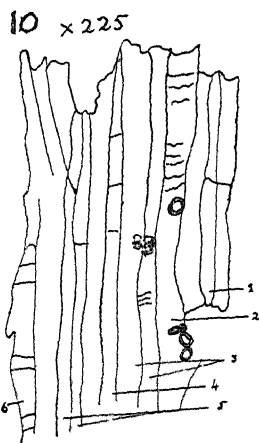
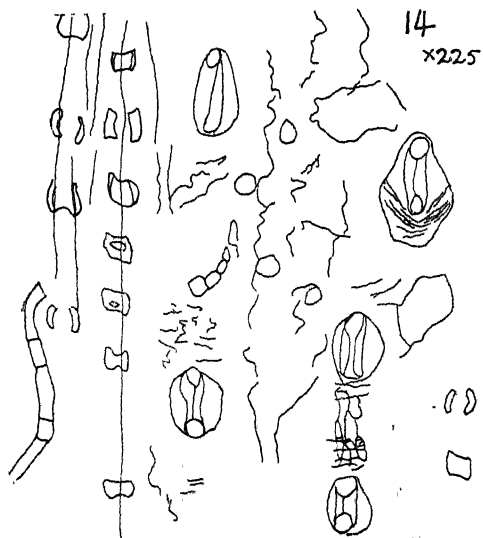
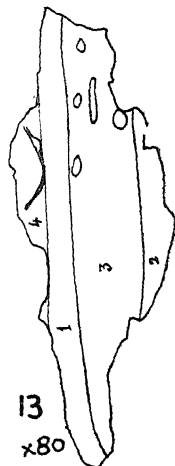
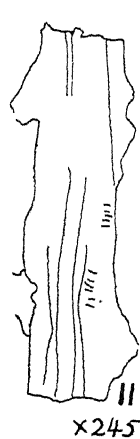
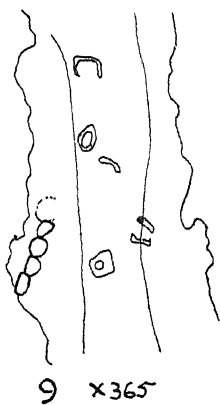
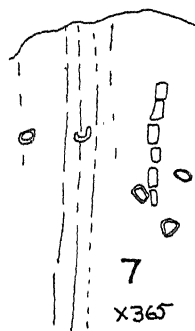
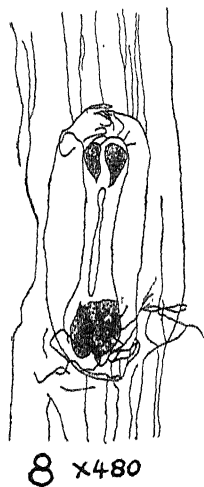
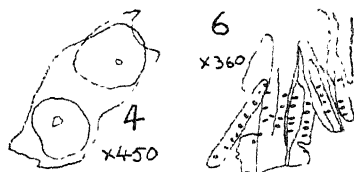
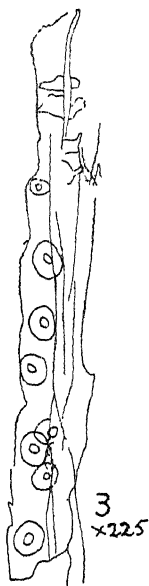
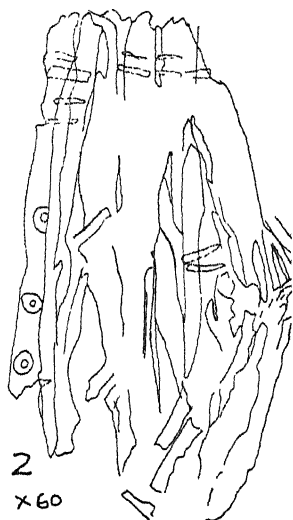
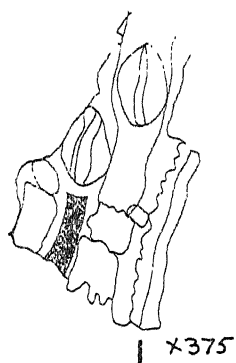
Sample: Phillips Nos. 1-5. (Salt and Marl).

(a) A badly preserved piece of wood, (Text-fig. 9) with the central portion better preserved than the peripheral. Thickenings are visible only in the central portion. They may have been annular, spiral or reticulate in the original condition but under the present state it is difficult to be sure of their true nature. Silica cell like structures occur scattered all over the surface of the wood. Some of the well preserved ones measure 10.4μ in length and 7.8μ in width. They occur both in the central as well as in the peripheral portions. Fungal hyphae as shown on the left hand margin of the (Text-fig. 9) are also present.

(b) A very well preserved piece of wood (Text-fig. 10). The wood shows a radial longitudinal face. On the extreme right side of the wood are

TEXT-FIGURES 1-14, MICROFOSSILS FROM SALINE ROCKS OF KHEWRA.

- (1-4). Camera lucida sketches of microfossils from a sample consisting mostly of Marl. (Sample: Sahni No. 1). (1) Cuticle of one of the gramineae, with stomata and sinuous-walled epidermal cells. (2) Gymnosperm wood with bordered pits and broken bands of medullary ray. (3) A portion of the above magnified. (4) Piece of a tracheid with two big bordered pits.
- (5-8). Camera lucida sketches of microfossils from a sample of Rocksalt (Marl excluded as far as possible) (Sample: Sahni No. 1). (5) Anterior part of the thorax, probably of a Collembolan larva. (6) Tissue of cells with simple pits. (7) A membranous structure with a few silica cells. (8) A big stoma probably of a grass.
- (9-14). Camera lucida sketches of microfossils from a sample of Salt and Marl, both almost equal in quantity. (Samples: Phillips Nos. 1-5). (9) Tissue with disorganised silica cells and fungal cells. (10) Piece of wood with annular and spiral or scalariform? thickenings. (11) Badly preserved wood with traces of scalariform sculpture. (12) Wood with simple pits, infested with some fungus. (See also 15). (13) A grass cuticle. (14) A portion of the above magnified, showing stomata, silica cells and some disorganised epidermal cells.



visible long parenchymatous cells (1). They are 67.6μ long and 7.8μ wide with thin walls (no lignification of walls is perceptible), and are devoid of any cell contents. Adjoining the parenchymatous cells occur some loosely lying annular rings, 7.8μ in diameter, (2). Next to the annular layer of the xylem is (3), the metaxylem. The sculpturing of this layer is not very well defined. The bands of thickening are very much disorganised, thus making correct identification difficult. The layer next to the xylem elements (4), is composed of two rows of longitudinally disposed cells measuring about 28.6μ in length and 5.2μ in width. The next layer (5), is composed of empty, narrow, longitudinally running tubular, septate cells; the septa are, however, very far removed from each other. The outermost layer (6), is again parenchymatous. Some cells are long and broad, others small and narrow.,

(c) A poorly preserved piece of wood (Text-fig. 11) which shows at one of its edges a few remains of badly preserved scalariform thickenings.

(d) A piece of wood composed of compacted vessels (Text-figs. 12, 15). The vessels vary from 13μ to 18μ in width, some of them being even narrower. Pits, simple round or elliptical. Obviously an angiosperm wood. Septate fungal hyphae are also visible.

(e) A large well preserved piece of cuticle with a large number of septate fungal hyphae sticking to its surface (Text-fig. 13). Only a portion of it is shown in (Text-fig. 14). (*See also Sahni, 1944a, Fig. 4, p. 56*).

The stomata are arranged in a linear way as is common in grass cuticles (Text-fig. 14). In the entire piece of cuticle about 16 well preserved stomata are seen arranged in two longitudinal rows: one row has 6, while the other has 10. Most of the stomata are well preserved but a few have become distorted. The cuticle is divisible into 4 zones, (see Text-figs. 13; 1, 2, 3, 4) two of which (1 and 2) (and also the left side of Text-fig. 14) are occupied by silica cells without any stomata; the third (right side of Text-fig. 14) is the central or stomatal zone without any silica cells, and the fourth zone not shown in Text-fig. 14, has badly preserved cells; here only the fungal hyphae are well preserved. The epidermal cell walls are poorly preserved, but their sinuous nature is clearly seen in places. The silica cells are very numerous and are as a rule well preserved. They are (zone 1) in two parallel longitudinal rows and mostly shaped like a double concave lens or like a short dumb-bell. Each silica cell on the average is about 10.4μ in length and as much in width at the thickest point. Fibres lying below the epidermis are seen running throughout the length

of the silica cell zone. Septate fungal hyphae, occur all over the surface of the cuticle. The central zone is occupied by stomata of a very characteristic type which measure about $26\mu \times 20.8\mu$. Stomata of this type are characteristic of the grasses.

(f) A piece of cuticle in which some of the cell walls are well preserved (Text-fig. 16). No stomata are preserved. Three hair like appendages emerging from the cuticle are seen at a, b and c. Two of them (a and b) are simple conical projections, broad at the base and tapering to a point apically. The third appendage (c) is curved and is composed of three unequal cells. Spread over the cuticle is a fungus which forms a septate mycelium.

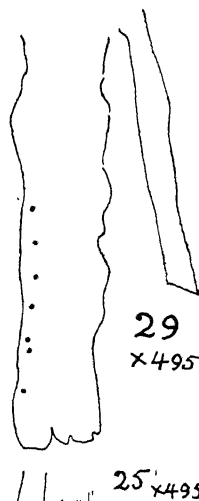
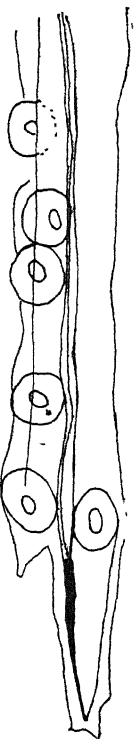
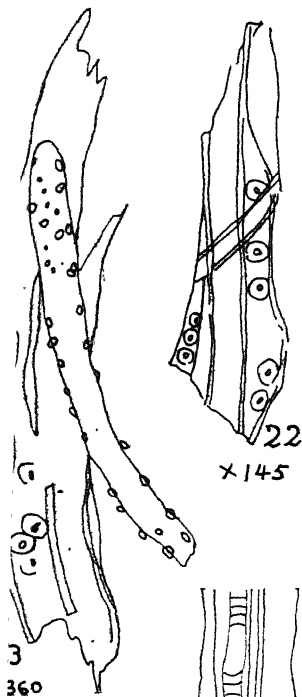
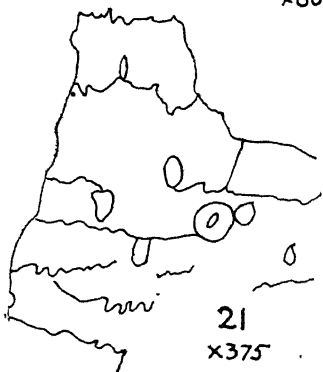
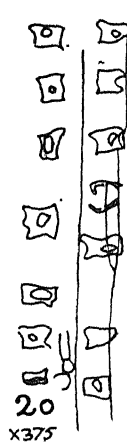
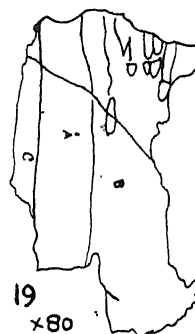
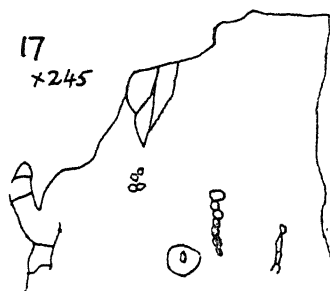
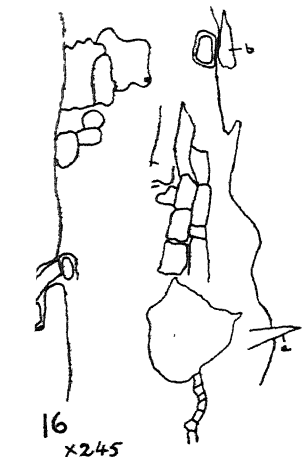
(g) A piece of cuticle, with only a few surface features preserved (Text-fig. 17). The cuticle has a round circular scar, in the centre of which is a pore (Text-fig. 18). On one side of the cuticle is present a three celled appendage. A fungal hypha (on the left side of the scar in fig. 18), composed of short round cells is also visible. The fungal cells are thick walled and roundish. No stomata are preserved in the cuticle.

(h) A piece of cuticle (Text-figs. 19, 20 & 21) (See also Sahni, 1944a, Figs. 5 and 6, p. 56). The cuticle is divisible into three distinct zones (See A, B, C in Text-fig. 19), two of which (B and C) are similar and the third central zone (A), is different from both these. The zone (A) consists mainly of silica cells; the epidermal cells are very poorly preserved. On either side of the zone (A) are zones (B) & (C) which are composed of thin-walled epidermal cells with well preserved sinuous outlines. These cells have numerous small pinhole like structures, (perhaps, the punctations); these are circular or slightly elongate in shape, measuring about 1 to 1.5μ in diameter. Besides the punctations, a few bigger scars, about 10.4μ long, are also present. The central zone (A) of the cuticle has numerous silica cells, they vary both in shape and size. Pieces of septate fungal hyphae are scattered over the surface of the cuticle.

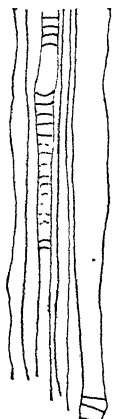
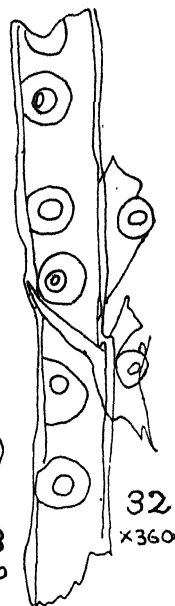
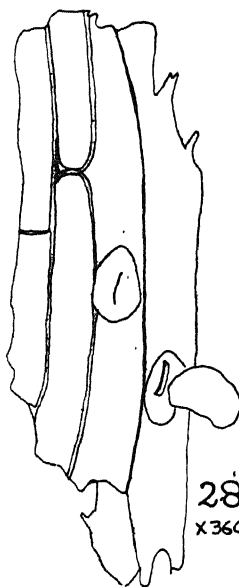
Sample: K₄ (Salt and Marl).

(a) A shred of coniferous wood (Text-fig. 22). (See also Sahni, 1945 Figs. 3 and 4, p. 7). The bordered pits are very faint; they are circular and are visible with difficulty.

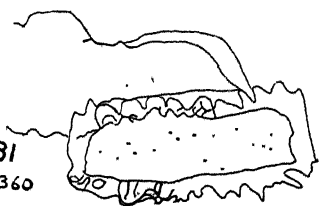
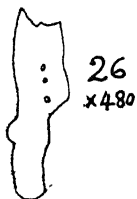
(b) A piece of gymnospermous wood with several elliptical, contiguous, uniseriate or alternate bordered pits (Text-fig. 23). A long cylindrical body with pointed ends is also associated with this piece. It is more deeply stained than the rest of the wood and has a large number of small elliptical thick walled



25
x495



26
x480



bodies attached to its surface. This body evidently has nothing to do with the wood.

(c) A very well preserved piece of gymnosperm wood with large bordered pits (Text-fig. 24) (*See also Sahni, 1945, Fig. 5, p. 7*). Only two incomplete tracheids are preserved. Pits slightly elliptic, uniseriate, contiguous or separate.

Sample: K₅ (Salt and Marl).

(a) A badly preserved piece of wood which has undergone disintegration (Text-fig. 27). Some indications of a faint scalariform sculpturing are, however, visible.

(b) A piece of cuticle (Text-fig. 28) (*See also Sahni 1945, Fig. 6, p. 9*) with three stomata, longitudinally aligned. The cuticle is composed of many rather thick walled cylindrical cells 13μ wide and several times as long. The cell walls are straight, and not sinuous. The stomata (about 26μ long and about 16μ wide) are badly preserved: much of their structure is lost. Hair bases or silica cells absent. Affinities unknown.

Sample: K_{6a}. (Salt and Marl).

(a) Badly preserved piece of wood (Text-fig. 29). Pits minute, in a longitudinal series, circular, simple and separate.

(b) A small piece of well preserved wood consisting of several scalariform xylem cells (Text-fig. 30). (*See also Sahni 1945, Fig. 7, p. 9*). The small

TEXT-FIGURES 15-32, MICROFOSSILS FROM SALINE ROCKS OF KHEWRA.

(15-21). Camera lucida sketches of microfossils from a sample of Salt and Marl, both almost equal in quantity. (Sample: Phillips Nos. 1-5). (15) A portion of the tissue in Text-fig. 12, further magnified. (16) Cuticle with three appendages. (17) Cuticle with an appendage on the left. (18) A portion of the above further magnified (shown upside down). (19) A cuticle with silica cells and sinuous walled epidermal cells (for details see 20 and 21). (20) silica cells from the above cuticle, further magnified. (21) Epidermal cells with sinuous walls from the above cuticle, further magnified.

(22-24). Camera lucida sketches of microfossils from a sample of Salt and Marl. (Sample: K₄). (22) A piece of Gymnosperm wood with bordered pits. (23) Gymnosperm tracheids with bordered pits; associated with them on one side is an unknown body. (24) Coniferous tracheids with clear big bordered pits.

(25-28). Camera lucida sketches of microfossils from a sample of Salt and Marl (Sample: K₅). (25) Disorganised piece of wood with simple pits. (26) A small piece of carbonised wood with simple pits. (27) Wood with scalariform thickenings. (28) Cuticle with badly preserved stomata and large straight-walled epidermal cells.

(29-31). Camera lucida sketches of microfossils from a sample of Salt and Marl (Sample: K_{6a}). (29) A piece of wood with simple pits. (30) Tracheids with scalariform thickenings. (31) Disorganised cells with small pits and thick plicated walls.

(32). Camera lucida sketch of a gymnosperm wood with bordered pits from a sample of Salt and Marl (Sample: K₇).

scalariform rods cannot all be clearly brought out in one focus as they lie at different levels.

(c) Two cells with a very peculiar structure (Text-fig. 31). One of the cells has a thick wall which is very much plicated (contorted) and about 5.2μ thick.

Sample: K₇. (Salt and Marl).

A well preserved piece of gymnosperm tracheid (Text-fig. 32). (*See also Sahni 1945, Fig. 8, p. 9*). Pits large, bordered, circular or slightly elliptic, separate and uniseriate.

Pt. I (B). MICROFOSSILS FROM SALINE ROCKS OF WARCHHA.

Sample: Sahni No. 1. (Salt free from Marl).

(a) A piece of carbonised wood (Text-fig. 33). It bears small conical projections, probably the broken ends of cells that might have constituted a 12 to 13 cells high medullary ray. Pits small, simple, circular to elliptic.

(b) A piece of wood with 8 bordered pits (Text-figs. 34, 35 & 36). Pits bordered, elliptic or circular. In one of them, cross pores are also visible.

Sample: Sahni No. 1. (mostly Marl, Salt excluded).

(a) A well preserved piece of wood which includes a portion of a medullary ray (Text-figs. 37, 38). The medullary ray is two cells high and at least five cells deep. In some of the medullary ray bars pits in the tangential view are visible. Pits on the radial walls of the tracheids are all simple, elongate and slit like. This wood no doubt belongs to an angiosperm.

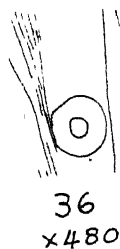
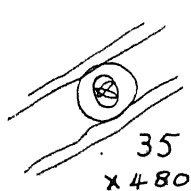
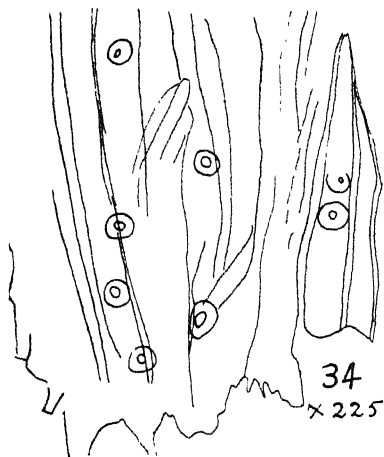
TEXT-FIGURES 33-48. MICROFOSSILS FROM SALINE ROCKS OF WARCHHA.

(33-36). Camera lucida sketches of microfossils from a sample of Rocksalt, Marl being excluded as far as possible. (Sample: Sahni No. 1). (33) Carbonised tracheids with simple pits and indications of medullary ray bars. (34) Gymnosperm wood with bordered pits. (35-36) Portions of the above further magnified to show the details of the bordered pits.

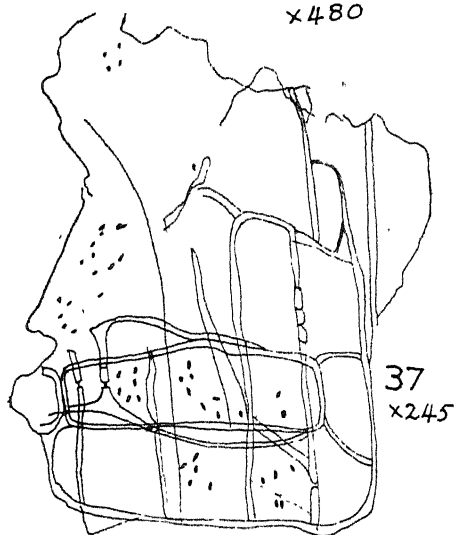
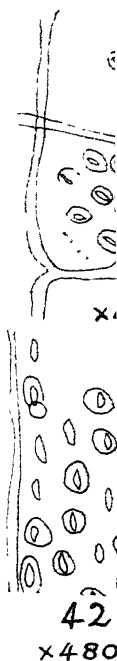
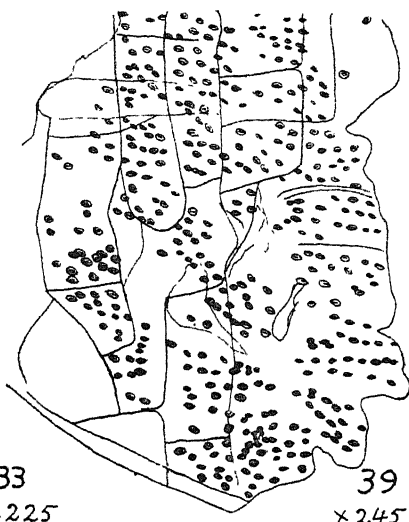
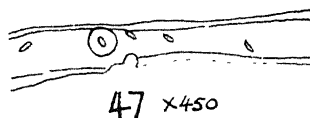
(37-45). Camera lucida sketches of microfossils from a sample of Salt and Marl: mostly Marl, Salt being removed as far as possible (Sample: Sahni No. 1). (37) A piece of wood with simple pits. (38) A portion of the above to show the details of the pits. (39) Wood with bordered pits and medullary rays. (40) A portion of the above further magnified. (41) Angiosperm wood with pits and medullary ray bars. (42) A portion of the above further magnified. (43) A small piece of angiospermous wood with simple pits. (44) Peculiar filamentous body (45) A portion of the above to show the detailed structure.

(46-47). Camera lucida sketches of microfossils from a sample of Salt and Marl, both almost in equal quantity. (Sample: Lamba No. 2). (46) Branched filamentous shred of woody tissue. (47) A portion of the above further magnified to show pits. Probably all the pits were originally bordered, but most of the borders are no longer preserved.

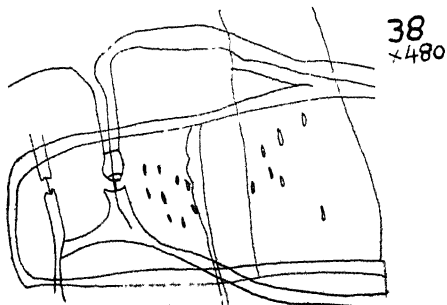
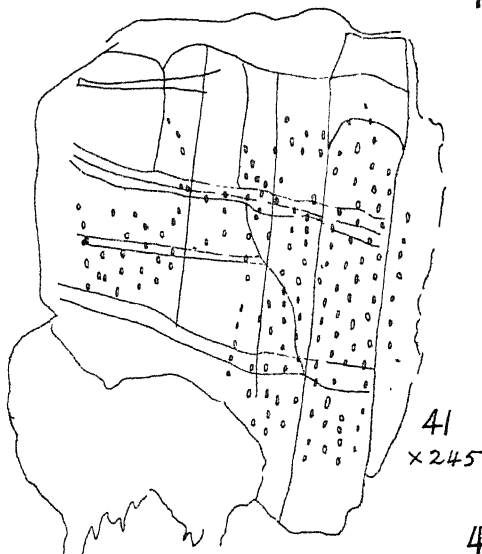
(48). Camera lucida sketch of a pitted cell from a sample of Salt and Marl. (Sample: Lamba No. 5).



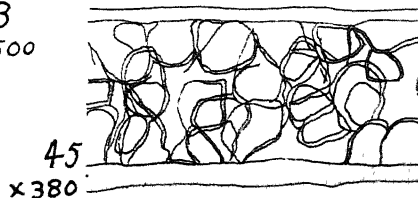
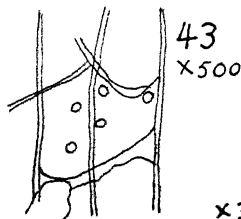
33
x 225



48 x 480.



46
x 78



(b) A well preserved piece of wood with numerous multiseriate bordered pits (Text-figs. 39, 40). Pits bordered, elliptical, placed with their longer axis transversely or obliquely to the length of the cell. The pores narrowly elliptical or slit-like. Obviously, this is also a typically angiospermous wood.

(c) A piece of wood composed of pitted rectangular cells (Text-figs. 41, 42). Pits bordered, circular or elliptical, pores elongate or lenticular. A pit on the tangential wall of the wood is also visible. The structure of this wood is also angiospermic.

(d) A well preserved compact piece of wood (Text-fig. 43), composed of numerous vessels. Pits simple, circular and crowded.

(e) A filamentous cylindrical structure, incomplete at both ends. About $2,000\mu$ of the length is preserved (Text-figs. 44, 45). The wall is about 5.2μ to 7.8μ thick and finely laminated, as is specially evident at places where it is broken. Within the lumen of the filament is a very curious net like structure with a number of small black carbonised fragments. The lumen of the filament measures about 49.4μ in width.

Two other specimens from very diverse localities identical with this fossil have been recovered. One of them was prepared by Prof. Sahni from a sample of oil shale (S/57) from the Fatehpur Maira Gorge, Salt Range, Punjab; the other was found by myself in a core sample of shale (P.A. 19) from the Barails of Assam. (Baragolai well 1, Barails-Group 8. Depth: 3,338 ft. to 3,344 ft.) The Barails are supposed to be upper Eocene in age (*Evans and Sansom* 1941, p. 325).

I thank the Burmah Oil Company for allowing me to publish this note on this form.

Sample: Lamba No. 2. (Salt and Marl).

A black, compound fibre-like structure about 26μ thick (Text-fig. 46). It divides at one end into three narrow fibrils. Five slit-like pits are seen in one of the branches (Text-fig. 47). In one pit a slightly elliptical border is discernible. The fossil appears to be a shred of woody tissue.

Sample: Lamba No. 3. (Salt and Marl).

A well preserved rectangular cell with a large number of small simple pits (Text-fig. 48). Pits small, elliptical and irregularly distributed.

Pt. II (A). MICROFOSSILS FROM DOLOMITIC ROCKS OF
WARCHHA.

Sample: S/21 I.

(a) A piece of badly preserved and disintegrated wood (Text-fig. 49). Only one oval bordered pit is present.

(b) A badly preserved piece of wood (Text-fig. 50) which has lost all surface sculpture. A medullary ray is, however, visible.

(c) A piece of wood (Text-fig. 51), with a large number of very small irregularly arranged simple pits. Two circular holes much larger than the pits are also visible.

(d) A black carbonised woody fragment (Text-fig. 52). It has about twelve very small simple pits. They are separate and irregularly arranged.

(e) A badly preserved small piece of wood (Text-fig. 53). Two bordered pits are visible.

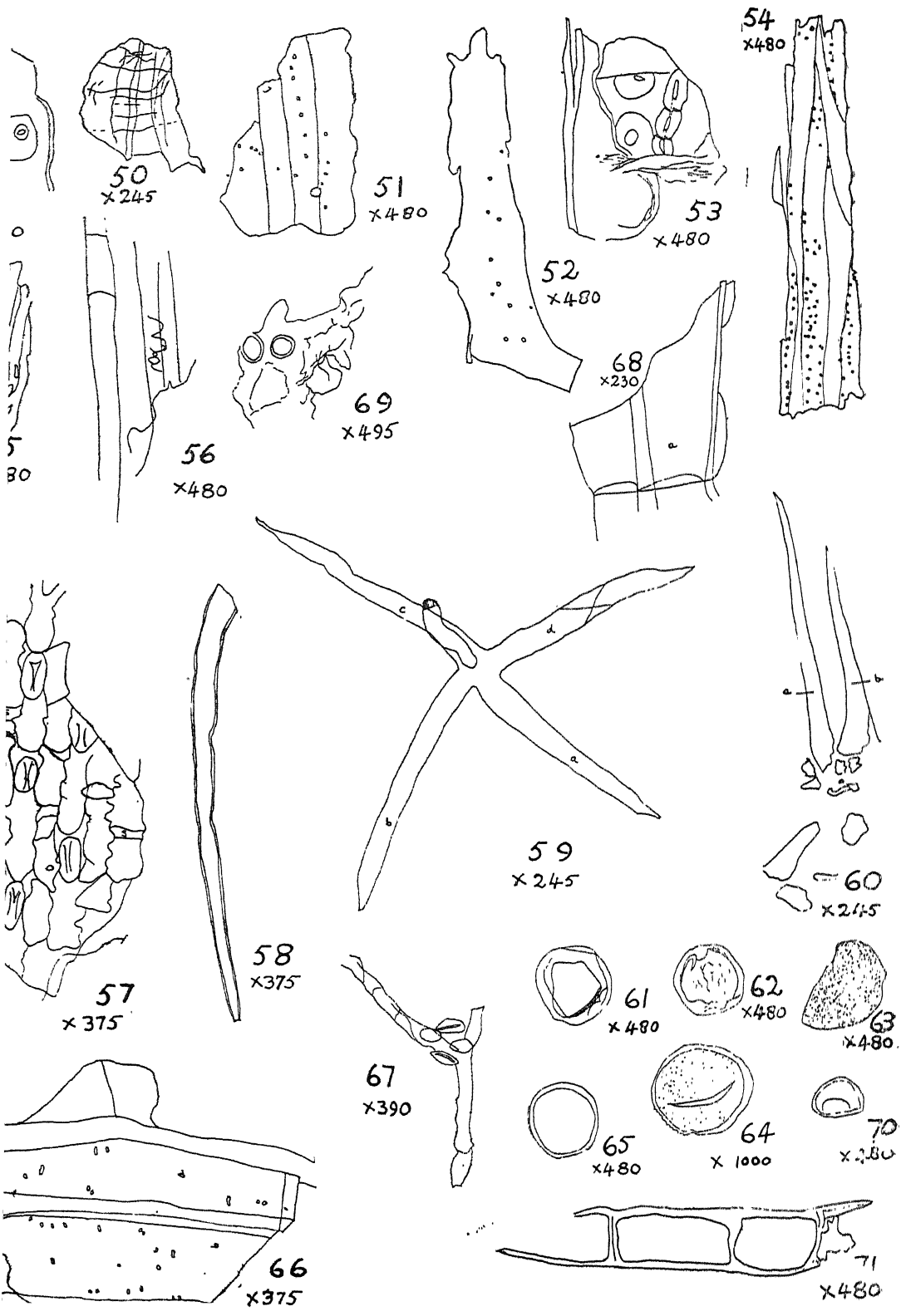
(f) A well preserved carbonised piece of wood (Text-fig. 54); about six tracheids are present. Pits simple, circular, multiseriate.

(g) A small piece of wood (Text-fig. 55) which shows three slightly deformed simple pits in one of the tracheids. Some indication of pits in the other tracheids are also discernible. The pits are lenticular in shape.

(h) A badly preserved piece of wood. Only some vague indications of thickenings (Text-fig. 56) can be seen. The tissue has become transparent due to decay.

(i) A well preserved piece of cuticle (Text-fig. 57) (*See also Sahni 1944a, Fig. 12, p. 60*). The cuticle is composed of seven rows of rectangular sinuous-walled cells. The stomata are longitudinally aligned and are arranged in two rows; one row has three stomata, the other two. The row containing three stomata has a rudiment of a fourth stoma as well. The stomata are elongate and measure 16μ in length and 10μ in width. Between the septa of the two adjacent epidermal cells is sometimes present a small transparent cell (*s*). This may be a short cell, (*Prat, 1932, p. 126*).

(j) A single well preserved non-septate hair about 182μ long (Text-fig. 58). The hair is 13μ wide at the base but narrows considerably and measures 2.6μ at the apex. A little constriction in the middle of the hair is visible. The wall of the hair is moderately thick.



(k) A very well preserved stellate epidermal hair (Text-fig 59). (See also Sahni, 1944a, Fig. 13, p. 60). It has four long arms radiating from the centre, and one short stout structure, perhaps the stalk. The arms are (a) 147μ , (b) 163μ , (c) 178μ and (d) 168μ long. The stalk is 52.2μ long. Each arm tapers gradually from the base and ends pointedly. The walls of the arms are well preserved. In one of the arms small longitudinal striations are seen. The arm (d) is twisted upon itself at one point. The stalk is slightly curved and has a small cap like structure attached to its free end.

(l) Two well preserved hairs (Text-fig. 60). They measure (a) 195.3μ and (b) 128μ , in length. The hair (a) is 16.8μ and (b) 23μ in width, at the base. They have a triangular to roundish base; from base onwards their width decreases steadily till they gradually taper out as long drawn out structures. They have very pointed apices. At the base of the hairs a badly crushed tissue without any clear cell walls is preserved.

(m) A spherical spore measuring about 26.4μ in diameter (Text-fig. 61). No triradiate mark or germ pore is visible.

(n) A spherical spore about 23.4μ in diameter (Text-fig. 62). The surface of the spore has many small convolutions. Neither any germ pores nor a triradiate mark is visible.

(o) A thin-walled elongate? spore with a shagreen integument (Text-fig. 63). The spore measures 31.2μ in the longer axis and 18.2μ in the shorter. Indications of two folds are visible. There is no sign of a germ pore or of a trilete.

(p) A well preserved thick walled spherical spore (Text-fig. 64). It is about 13.6μ in diameter. Small crenulations in the wall of the spore are visible. The spore has a slit. The surface is shagreen.

TEXT-FIGURES 49-71, MICROFOSSILS FROM DOLOMITIC ROCKS OF WARCHHA.

- (49-69). Camera lucida sketches of microfossils from a sample of dolomite (S/21 I). (49) Piece of wood with a bordered pit. (50) Disorganised piece of wood with indications of a medullary ray. (51) Mineralised piece of wood with simple pits. (52) Carbonised piece of wood with simple pits. (53) Wood with bordered pits. (54) Carbonised tracheids with simple pits. (55) A piece of wood with three deformed simple pits. (56) Disorganised wood (57) Cuticle with sinuous walled epidermal cells and stomata. (58) Non-septate thick-walled hair. (59) Stellate hair with a stalk. (60) Two disorganised hairs with crushed basal cells. (61) Spore with folds. (62) Spore with convolutions on surface. (63) Spore with shagreen integument. (64) Thick-walled spore with a slit. (65) Thick-walled spore. (66) Tissue with thick-walled pitted cells. (67) Septate fungal hypha with four spores. (68) Shred of large-celled tissue. (69) Thin membrane (for details see text).
- (70-71). Camera lucida sketches of microfossils from a sample of dolomite (S/21 II). (70) Thick-walled spore with a fold. (71) Thick-walled empty cells.

(q) A circular body 23.4μ in diameter (Text-fig. 65). The exine is smooth and structureless.

(r) A shred of tissue consisting mainly of two large pitted cells lying side by side (Text-fig. 66). The longer cell is 135.2μ long and 39μ wide, the other is slightly shorter. The walls of the cells are from 5.2μ to about 10.4μ in thickness. The cells have a number of round or elongate simple pits. A few thin-walled cells form the rest of the fragment.

(s) A shred of thick walled tissue (Text-fig. 68). A thick longitudinal septum present in the middle of this piece appears to divide two large cells from each other.

(t) Some well preserved fungal spores with a little of the fungal mycelium (Text-fig. 67). The hypha is septate and the cell walls are well preserved. Four spores, two in one view and two in a different view, are visible. Two are boat shaped, 12.6μ long and 6.5μ broad, with a narrow longitudinal slit. The other two spores are different from these, both in shape and structure.

(u) A membrane full of small circular black bodies (Text-fig. 69). The membrane is rather peculiar in structure. Such membranes come out of the rock in plenty when the rock is dissolved in dilute HCl. They come out as thin flakes from within the fine laminations of the rock. The membranes are very resistant to the action of acids and oxidising agents. Even a mixture of conc. HNO_3 and KClO_3 boiled with the membranes does not destroy them. The black bodies in the membranes are, however, destroyed by this solution even in the cold, after a prolonged treatment. HCl hot or cold, dilute or concentrated, does not destroy the membranes nor the black bodies even after a prolonged treatment. The membranes take up safranin brightly. The dolomites S/21 I and S/21 II are full of such membranes. The black round bodies have left a circular area in the membrane from the places where they have been macerated out (Text-fig. 69). A rim like wall, round the cavities of the membrane, is clearly visible; this wall surrounded the black bodies when they were present in the membrane.

Sample: S/21 II.

(a) A well preserved thick walled spore (Text-fig. 70). The spore measures 16.2μ in the longer axis and 13μ in the shorter. The exine is finely granular.

(b) A row of thick-walled rectangular cells. Two complete cells and one incomplete cell are preserved (Text-fig. 71). The cell contents are all lost but the walls are persistent, they are 5.2μ thick.

Sample: S.R.E. 40.

A very transparent piece of a vessel of an Angiosperm. (Text-fig. 72.) (See also Sahni, 1945, Fig. 16, p. 13). The bordered pits as figured by Prof. Sahni were multiseriate and transversely elongate in arrangement. The structure has now become so transparent by mounting in Canada balsam that the pits have become almost invisible.

Sample: W₄.

(a) A deeply stained piece of wood disintegrated to such an extent as to lose all surface features (Text-fig. 73). No pits are preserved.

(b) A very well preserved piece of conifer wood with a large number of clearly preserved round bordered pits (Text-figs. 74, 75). (See also Sahni, 1945, Fig. 10, p. 11). My figures 74 and 75 represent portions of a single fossil which Prof. Sahni had figured in one piece. Two medullary rays cross the tracheids. A few pits in the field are also clearly visible (Text-fig. 75). The bordered pits are very clearly preserved and measure 13.0μ to 18μ in diameter. The pore is 5.2μ in diameter. Most of the pits are circular but some are elliptic, the pore conforming to the shape of the border. A few bordered pits are small, about 5.2μ in diameter. The main bordered pits are uniseriate and separate. Two medullary rays (a) in Text-fig. 74 and (b) in Text-fig. 75 cross the wood. One of them (a) is four cells high, the other (b) is only one cell high but shows a very clear group of four to five simple, obliquely placed narrowly elliptical or slit-like pits in the field, which measure about 5.2μ in length and 2.6μ in width. Some simple pits appear beyond the area of the field also.

(c) A well preserved piece of wood with six bordered pits (Text-fig. 76). Out of these, two are well preserved and two are poorly preserved. Two more very badly preserved pits were faintly visible and could not be figured. Pits bordered, separate, and circular.

(d) A circular thick walled spore-like body 23.4μ in diameter (Text-fig. 77). The wall is uniformly thick and smooth except at one place where it is thicker and slightly bulges out. No surface sculpturing is discernible.

(e) An elongated piece of tissue consisting of a number of parenchymatous cells (Text-fig. 78). They are in two layers, and each layer can be seen by changing the focus. Two types of cells, (a) long and (b) short, are visible. One of the longer cells of the upper layer measures 33.0μ in length and 15.6μ in width. The short cells on the average measure about 15.6μ in length and 13μ in width. Some cells are incomplete.

(f) A well preserved septate fungal hypha (Text-fig. 79). The cells are cylindrical and $1\frac{1}{2}$ to 3 times as long as broad.

Sample: W₇.

() A large, thick-walled pitted cell 70.2μ in length and about 28.6μ in width (at the broadest point) (Text-fig. 80). (See also Sahni, 1945, Fig. 11, p. 11). The cell has rather thick lateral walls the end walls have degenerated and are thinner. Pits, simple and mostly circular, but some are oval and elliptical as well. The cell wall is broken at many places. All the pits are not seen in one focus.

Sample: W₁₄.

(a) A piece of well preserved grass cuticle (Text-fig. 81). (See also Sahni, 1945, Fig. 12, p. 11). Sketch shows only a small part of the cuticle figured by Professor Sahni. The sinuous walls of the epidermal cells are clearly visible. The stomata are not preserved but three cavities arranged in two longitudinal rows—large enough to have lodged the stomata—are present. Some squarish cells measuring 10.4μ in length and 7.8μ in width are also seen. Each epidermal cell has a large number of punctations all over its surface. A few straight running fibrous strands below the epidermal cells are visible.

(b) A beautifully preserved stellate hair with five arms radiating from the centre (Text-fig. 82). (See also Sahni, 1945, Fig. 13, p. 11). Four of the arms are complete, the fifth is incomplete. One of the arms (e) is very much longer than the rest. In the centre of the hair is a cavity perhaps caused by the falling off of a central stalk which may have supported the hair. Round this cavity are three incomplete, short processes, like a corona these are 7.8μ to 10.4μ long. The arms have a broad base (about 12μ) and gradually

TEXT-FIGURES 72-85. MICROFOSSILS FROM DOLOMITIC ROCKS OF WARCHHA.

(72). Camera lucida sketch of an angiosperm wood with bordered pits from a sample of dolomite (S.R.E. 40).

(73-79). Camera lucida sketches of microfossils from a sample of dolomite (W₄). (73) Deeply stained structureless piece of wood. (74-75). Coniferous wood with medullary rays; small simple pits in the field are visible. (76) Gymnosperm wood with clear bordered pits. (77) Thick-walled round body, probably a spore. (78) Thin-walled plant cells. (79) Septate fungal hypha.

(80). Camera lucida sketch of a thick-walled pitted cell from a sample of dolomite (W₇).

(81-82). Camera lucida sketches of microfossils from a sample of dolomite (W₁₄). (81) Grass cuticle with sinuous walled epidermal cells and punctations. (82) Stellate hair with five arms.

(83-84). Camera lucida sketches of microfossils from a sample of dolomite (W₁₈). (83) Thick-walled pitted cell. (84) Stellate hair with four arms.

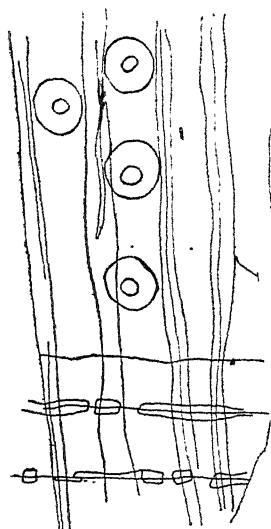
(85-86). Camera lucida sketches of microfossils from a sample of saline dolomite (W.S.D. No. 7).

(85) Gymnosperm wood with medullary ray; bordered pits not indicated. (86) A portion from the above, more highly magnified, to show pits.

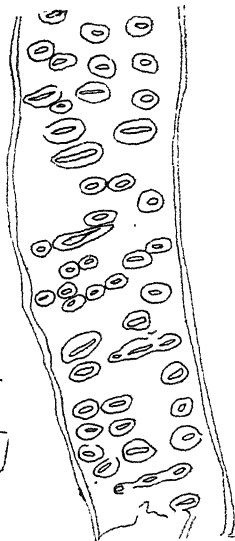
TEXT-FIGURES 87-88, MICROFOSSILS FROM DOLOMITIC LIMESTONE OF KHEWRA.

(87-88). Camera lucida sketches of microfossils from a sample of dolomitic limestone (K.D.L.L. III).

(87) Angiosperm wood with scalariform thickening (for details see 89). (88) Carbonised wood with simple pits.



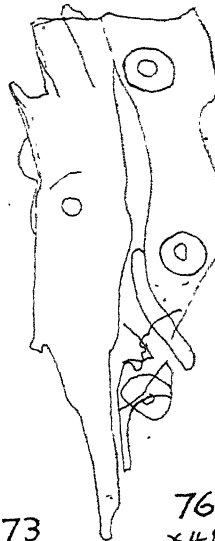
86
x 380



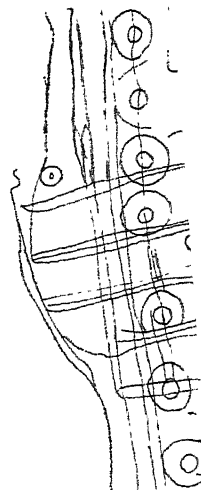
72
x 500



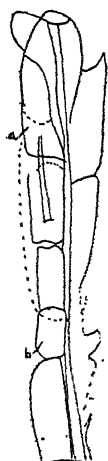
73
x 480



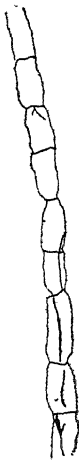
76
x 480



74
x 380



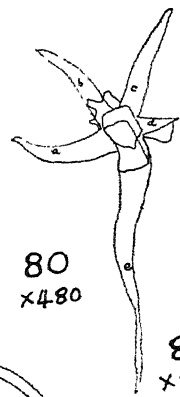
78
x 390



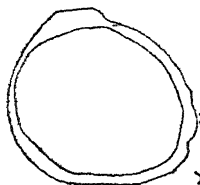
79
x 480



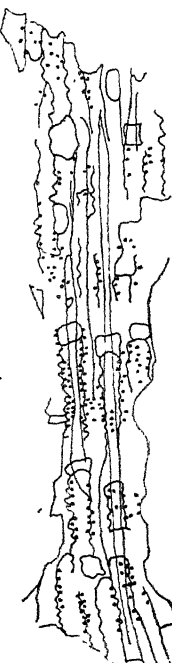
80
x 480



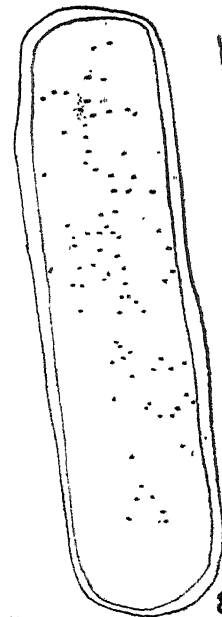
82
x 245



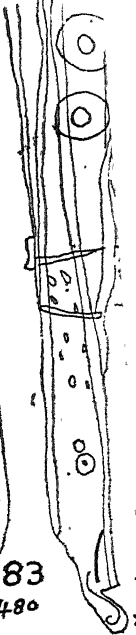
77
x 1000



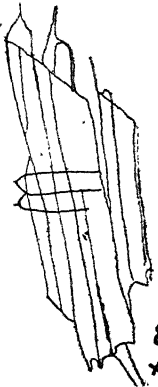
81
x 380



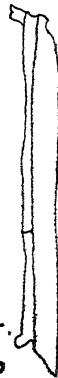
83
x 480



84
x 48



85
x 80



87
x 80



88
x 480

taper towards their apices. The three arms (a), (b) and (c) measure from 52μ to 57μ in length. The fourth arm (d) is incomplete. The fifth arm (e) is the longest, it is 117μ long and has a long drawn out apex. The cell wall of the arms is rather thin. There is no sign of a septum in any of the arms.

Sample: W_{15} .

(a) A multicellular stellate hair embedded in a mucilaginous mass (Text-fig. 84). It has four appendages which come out from a central knob like structure. Two appendages are septate and two are apparently non-septate. They are about 52μ long and about 5.2μ wide. The septate arms have 2 to 3 septa each. Two of the arms end rather bluntly, the others are incomplete.

(b) A long transparent pitted cell of large size (Text-fig. 83). By changing the focus fine laminations in the wall are visible. Very small pin-hole like simple pits are visible.

Simple: *W.S.D. No. 7.*

A well preserved piece of wood composed of thick-walled tracheids with bordered pits (Text-figs. 85, 86). (See also Sahni, 1944a, Fig. 10, p. 59).

A large number of adhering dust particles and carbonised fragments mar the clear visibility of the bordered pits. A two cells high medullary ray crosses the tracheids. Pits in the field are not visible, but the thick horizontal walls of the medullary ray cells are distinctly pitted. The bordered pits are circular or slightly elliptic, uniseriate and separate.

Pt. II (B). MICROFOSSILS FROM DOLOMITIC LIMESTONE KHEWRA.

Sample: *K.D.L.L. III.*

(a) A very well preserved piece of wood. (Text-figs. 87, 89). One side of this piece (See Text-fig. 89) is composed of a narrow tube like structure (a); it is thin walled, non-septate, and measures from 5.2μ to 7.8μ in width. Next to this layer is a well defined thin-walled two layered tissue about 7.8μ in width. This layer shows oval and circular pits. The pits are uniseriately arranged, and vary greatly in size. The central portion (c) of the wood measures about 18.2μ in width. It has a characteristic scalariform type of thickening. There are one to three simple pits in one transverse row. One and three pits are uncommon but two are very common. Two bordered pits are also seen. The two layers (a) and (b) described above occur again on the other side of the central zone (c), but in a reverse order. The layer (b) corresponds to layer (d) and (a) to (e).

(b) A carbonised piece of wood (Text-fig. 88). It has a number of elongated simple pits; two of them are deformed.

Pt. III (A). MICROFOSSILS FROM THE OIL SHALES OF WARCHHA.

Sample: S/20.

(a) A piece of carbonised wood with two very minute pinhole like simple pits (Text-fig. 90).

(b) A well preserved piece of wood with five simple pits (Text-figs. 91, 92). Some pits are circular and uniseriate but a few have become slit like due perhaps to pressure. The walls of the tracheids are thick, the lumen is narrow.

(c) A badly preserved piece of wood with two or three tracheids (Text-fig. 93). The tracheids are crossed by a three cells high medullary ray of thick-walled cells. No pits are visible but a very faint indication of a bordered pit occurs. The nature of this pit is very doubtful.

(d) A piece of carbonised wood, not very well preserved (Text-fig. 94). Pits simple, circular and pinhole like.

(e) A piece of carbonised wood with two cavities (Text-fig. 95). No pits are preserved.

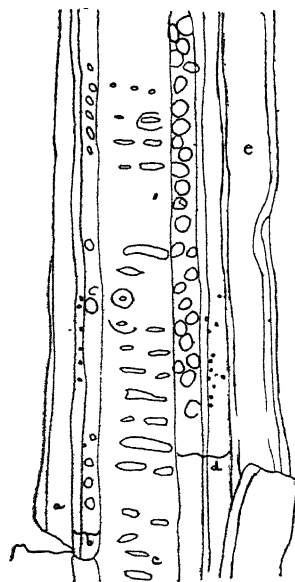
(f) A well preserved septate hair (Text-fig. 96). Distally it has a conical beak like apex. The hair is 198.0μ long and 13μ wide at the thickest point. The wall is 2.6μ thick, the lumen is 7.8μ wide. Two septa divide the hair into three unequal cells. The proximal cell (a) is the smallest, being only 20.8μ long. The second cell (b) is 31.2μ long. The third and the longest cell (c) is 143μ long. This cell gradually tapers but before finally ending bends slightly to one side. In the middle of the cell (c) is an indication of a fold (which in the figure looks like a septum).

(g) Dark spherical bodies (See (c) under S.R.E. 38).

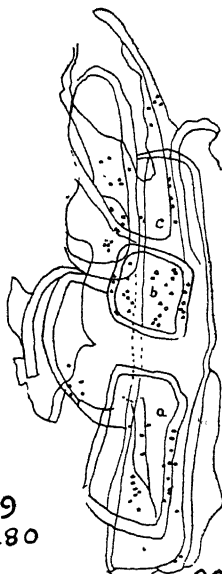
Sample: S/20 II.

(a) A spherical thin-walled spore with a wide central slit (Text-fig. 98). It is 26μ in diameter. The exine is finely granular.

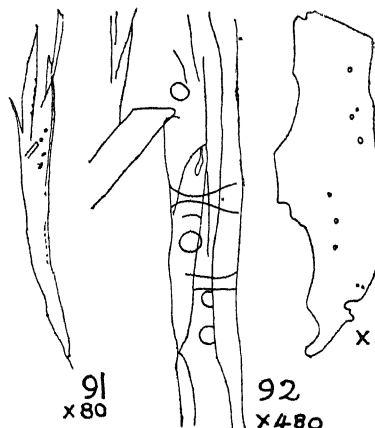
(b) A well preserved piece of tissue in two layers (Text-fig. 99). One layer is composed of three cells in one row; two of these are complete, the third is incomplete. The cells vary greatly in size, one of them (a) is 37.6μ long, the cell next to it (b) is 23.4μ long and the incomplete one (c) is about 65.9μ long. In the other layer only one very large incomplete thick-walled cell 109μ long is seen. The cells of the first layer have many simple circular or oval pores. The walls of these cells are 2.6μ thick; no middle lamella is preserved. Associated with the cells is some disorganised material, probably a degenerate product of the cells themselves. No cell contents are visible.



89
x480



99
x480

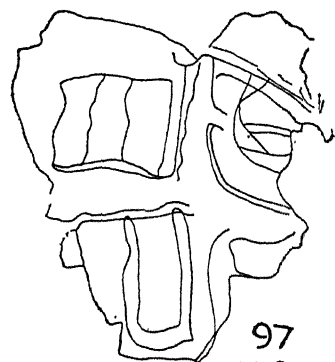


91
x80

92
x480

94
x480

90 x495



97
x480



95
x480



93
x480



98
x480



96
x380



101
x480



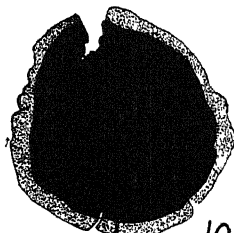
102
x480



103
x480



100
x365



104
x160

Sample: S.R.E. 38.

(a) Pieces of carbonised wood with small pinhole like simple pits (Text-figs. 101, 102). (*See also Sahni, 1945, Fig. 15, p. 13*). In one piece, only three pits are seen (Text-fig. 101). In the other (Text-fig. 102) a few more pits are visible.

(b) A piece of carbonised wood embedded in the thin section of the oil shale from Warchha (Text-fig. 103). It is 104μ long and 28.6μ wide. Pits simple, separate, circular and uniseriate. Tracheid walls are not visible. Lying close to this piece is another carbonised piece without pits.

(c) A large black circular body (Text-fig. 104). It is surrounded by a thick fibrous membrane-like wall. The body is almost round, about 192μ in diameter. The wall is about 16μ thick and brownish in colour, the centre is black. Such round bodies are also seen in thin sections prepared from S/20 an oil shale from Warchha.

Pt. III (B). MICROFOSSIL FROM THE OIL SHALE OF MAKRACH.

Sample: S.R.E. 19.

A piece of carbonised wood with a number of small simple pits (Text-fig. 100). (*See also Sahni, 1945, Fig. 14, p. 13*). Some of the pits are very small, like pinholes. The pits are uniseriate or biseriate. The tracheid walls are thick.

2. ANIMAL REMAINS.

Ten well defined species of insect remains, six from the saline rocks, three from the dolomites and one from the oil shales have been recovered. These form the subject of two papers by M. S. Mani.

TEXT-FIGURE 89, MICROFOSSIL FROM DOLOMITIC LIMESTONE OF KHEWRA.

(89). A portion of Fig. 87, more highly magnified (Sample: K.D.L.L. III).

TEXT-FIGURES 90-99 & 101-104, MICROFOSSILS FROM OIL SHALES OF WARCHHA.

(90-97). Camera lucida sketches of microfossils from a sample of oil shale (S/20). (90) Carbonised woody piece with two small simple pits. (91) Wood with simple pits. (92) A portion of the above, further magnified. (93) Woody piece with medullary rays. (94) Carbonised wood with simple pits. (95) A piece of carbonised wood. (96) Septate hair. (97) Tissue, with cell like structures.

(98-99). Camera lucida sketches of microfossils from a sample of oil shale (S/20 II). (98) Spore with a shagreen integument and a wide slit. (99) Shred of tissue with thick-walled pitted cells.

(101-104). Camera lucida sketches of microfossils from a sample of oil shale (S.R.E. 38). (101) Broken pieces of a carbonised wood with simple pits. (102) Carbonised tracheids with simple pits. (103) Carbonised tracheids with simple pits, embedded in a thin section of the rock. (104) Dark opaque body with yellowish fibrous outer layer.

(Text-fig. 100). Camera lucida sketch of carbonised tracheids with simple pits from a sample of oil shale from the Nawabi Kas, Makrach (S.R.E. 19).

In his earlier paper (Mani, 1944, *Ind. Journ. Ent.* **6** : 61-64a) Mani has described a complete insect *Chironomus primitivus* sp. nov. from the Saline Series. In the same paper he has also described two specimens of forelegs of some aphids, whose real affinity is doubtful.

In order to strengthen the evidence since the publication of his first paper (*op. cit.*) he has emphasised certain salient characters of those forms again in the present paper (Mani, 1946). He has also fully described the specimen sketched in Text-fig. 5.

As Mani has given all the details regarding the localities and the kind of rock from which the fossils were obtained I will not repeat what has already been said.

SUMMARY OF ORIGINAL OBSERVATIONS

The chart below (p. 207) gives a generalised summary of the well preserved fossils that have been described in this paper. On summing up the total plant fossil content of all the rocks analysed we find that the angiosperm remains are dominant; they include woods, cuticles and various kinds of hairs which can only have belonged to flowering plants. Next to these are gymnosperm woods. Some forms cannot be definitely placed anywhere. There are also a few fungi of which the age cannot be easily judged.

A glance at the table will show that such an assemblage of plants cannot be so old as Cambrian or pre-Cambrian.

DISCUSSIONS OF AFFINITIES AND GEOLOGICAL AGE OF THE FOSSILS.

The microfossils recovered are mostly too fragmentary to be useful for establishing a relationship with the known groups of plants. However, some woods, most of the cuticles, some of the plant hairs, and a few insect remains, are relatively well preserved. The woods are mostly Angiospermous, a few are Gymnospermous; their reference to smaller plant categories is not possible. All the cuticles except three (Text-figs. 16, 17 & 28) have sinuous walled epidermal cells and longitudinally aligned stomata. They thus very closely resemble grass cuticles. One of them (Text-figs. 13, 14) resembles the cuticle of the Tribe Oryzeae of the family Gramineae. The stellate hairs are definitely Angiospermous because in no other group of plants do such hairs occur. The insect remains have been described by Mani; some of them have been referred to known groups, while one new species *Chironomus primitivus* Mani has been founded by him. Although the plant and the animal remains are not so well preserved as to be definitely datable yet collectively and individually they definitely point to a post-Cambrian age.

The Angiosperms are known with certainty only from the Lower Cretaceous onwards. Their existence prior to the Cretaceous period is extremely doubtful.

Palaeopitys Milleri, from the Middle Old Red Sandstone (*Kidston and Lang*, 1932) is the oldest bordered pitted wood known. The oldest gymnosperms are Devonian in age. The earliest land plants are known from the Middle Silurian of Australia (*Cookson*, 1935 ; *Lang and Cookson*, 1935). It is thus clear that the Angiosperms could not have extended so far back in time as the Cambrian or the pre-Cambrian periods. In fact the presence of land plants of any kind in those remote times is very doubtful.

It has been alleged that the fossils recovered are not indigenous to the rocks from which they have been macerated out, but are extraneous. All possible precautions against any foreign contamination were taken. The rock to be analysed was first cut on all sides; only the core was taken, this was rotated in a flame and then dissolved in filtered acid. If $KClO_3$ was used, it was dissolved, filtered and recrystallised. Under such circumstances the fossils could have come from no other source except the rock itself which contained them.

Some geologists claim that the oil shales and the dolomites may have been dissolved out and then redeposited incorporating within them the extra-

neous fossils. In the case of the oil shales at least this phenomenon is not known to happen. The fossils that we get from them are really authentic, and indicate their true age.

CONCLUSION.

The fossil evidence for the Tertiary age of the Saline Series is very strong. Many samples of the Rocksalt and Marl (both together and separately), dolomites and oil shales have been examined and repeatedly post-Cambrian fossils have been recovered from them. As has been suggested earlier by Mr. Gee on geological evidence alone, the fossil evidence also supports the idea that the Salt Marl, Dolomites and Oil Shales form one continuous sequence and are all members of the Saline Series. Thus whatever is true of the age of one of its stages is true for all the three. Stratigraphically it has been shown that the Saline Series can either be (1) Cambrian or pre-Cambrian or (2) Eocene. If a choice is therefore to be made between the alternatives, the fossil evidence unmistakably and unanimously points to the Eocene view.

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THE AGE OF THE PUNJAB SALINE SERIES. A REVIEW.

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Just at a time when we thought that, after all, the vexed controversy regarding the Cambrian versus the Eocene age of the Saline Series in the Punjab Salt Range had come to an end, and we were going to believe on the authority of Mr. Gee's elaborate field investigations during the years 1928-1934, that the saline beds were undoubtedly Eocene in age, came the astounding news in January, 1940 that Mr. Gee himself had abandoned this view and was actually supporting the Cambrian age. This meant that the old controversy instead of dying out as we thought it would, was still going to be very much alive; and it has more recently received further stimulus by the recent discovery of microfossils by Professor Birbal Sahni in these beds, the combined evidence of which, according to him, is entirely in support of the Eocene age and altogether rules out the idea of the Cambrian age. Thus "the old problem of the age of the Punjab salt is again in the melting pot" and the whole subject has been re-opened for further discussions; and a perusal of the several papers contributed to the Poona Symposium (December, 1944) on this subject will give us an idea of how sharply and strongly opinion is still divided on this intriguing problem.

From a review of all the literature on this subject from the days of Wynne right up to the present, it is clear that the solution of this problem ultimately depends on a proper understanding and interpretation of two aspects of the question: (i) stratigraphical and tectonic, and (ii) palaeontological; and for any conclusion being considered as being final and universally acceptable, it is obviously necessary that the entire evidence from both the aspects must be mutually complementary and not conflicting.

The recent discoveries of Professor Sahni have raised certain important considerations on the palaeontological side which indicate that the Saline Series is Eocene in age; and if this conclusion is to be accepted, we must be prepared to admit on the tectonic side the existence of an enormous overthrust which has affected the stratigraphical position of the Eocene Saline Series and placed them in an abnormal infra-Cambrian position, thus leading to the

conclusion that the junction of the saline beds with the overlying Palaeozoic beds is of the nature of a 'tectonic contact' and not a normal sedimentary one. If on the other, we feel that this interpretation of the tectonics of the area involving an enormous over-thrust is not supported by the actual field observations, and is therefore impossible, then the 'palaeontological evidence' of Professor Sahni has obviously to be further scrutinised to see if the testimony of these fossils as age indicators is established beyond all shadow of doubt. Thus the position has resolved itself once again into a right royal battle between the field geologist on the one side, and the palaeontologist on the other, each with his own evidences and arguments which appear to him all convincing.

Let us first take up for review and discussion the palaeontological aspect of the problem. As Professor Sahni has pointed out "Fossils found in the Saline Series in recent years have repeatedly suggested that the beds are early Tertiary or even younger. But the value of this evidence has been questioned; either the specimens were found on scrutiny to be indeterminable, or serious doubts arose as to their having been found *in situ*". As a matter of fact, one of the reasons why Mr. Gee recently gave up the Eocene view is that the palaeontological evidence on which, among other things, he had relied was on later examination found to be unreliable.

When one reads Professor Sahni's paper on his recent fossil finds and their evidences indicating a Tertiary age for the salt beds, the first question that one is naturally tempted to ask, especially if he is already strongly inclined to the Cambrian view, is whether Professor Sahni's material which has yielded all his palaeontological evidences does not come under the same category as Mr. Gee's which he has now discarded as undependable and misleading because of their not being truly *in situ* in character. Professor Sahni has of course anticipated this objection and has given reasons to assure us that all this rock material which has yielded the microfossils has been collected from true *in situ* occurrences of the bed. If on that point therefore we are satisfied, there seems to be no difficulty in accepting the conclusion based on the evidence of the contained microfossils in favour of the Tertiary age, seeing that the fossils themselves which are almost entirely composed of plant remains have been studied and identified by such an eminent authority as Professor Sahni.

There is, however, one other possible line of argument according to which an exacting critic might still feel sceptical about the convincing value of these microfossils as true indicators of the age of the containing beds. This line of argument would be somewhat as follows:

It is well known that in relying upon the contained fossils as age indicators of the containing bed, we must make sure that both the bed and the fossils contained in that bed are undoubtedly *in situ*. It is possible that a bed is truly *in situ*, but the fossils contained in it may not be; they may be 'derived' in which case they cannot obviously be used for age determinations. As already pointed out, Professor Sahni takes care to satisfy himself and assure us that the rock material from which he has recovered the microfossils comes from undoubtedly *in situ* occurrences of the bed in the field, and there can be no doubt that they are; but the question still remains whether the microfossils which are contained in them are truly *in situ*. At first sight, such a doubt seems altogether uncalled for in view of the fact that there is nothing to show that these microfossils are 'derived' fossils, as the term is ordinarily understood. But in the present case it must be remembered that we are dealing with a bed of salt which in many respects behaves very differently from the other usual sedimentary beds; for one thing, it is well known that this rock long after its formation is still very soft and plastic, and bits of foreign matter with which it comes into contact at any time subsequent to its formation can be enclosed and embedded in it quite easily,—a number of such instances where quite modern organic remains have been found enclosed in the salt having been reported every now and then. In referring to the reasons which led Professor Sahni to investigate the beds of the Saline Series for possible microfossils, he says: "If, as Christie has shown, these saline deposits are a product of normal sedimentation from salt lakes or lagoons, and if these lakes were exposed to the air at a period when land vegetation existed in any degree of profusion, we might reasonably expect to find, among the dust that blew on to the water's surface or in the material that was washed in, at least some microscopic specks of organic matter giving a clue to the life of the period". Now let us for a moment think of another state of affairs. Suppose that the saline beds are truly Cambrian in age, and were at the time of their origin quite unfossiliferous. It is possible that some of these salt beds were exposed to the air on the surface at some time or other during the early Tertiary periods, and these areas were surrounded by land where there was profuse vegetation of all sorts as there would be during the Tertiary times, then it is quite possible, under these conditions, that microscopic specks and fragments of organic matter,—'organic dust'—from the surrounding vegetation which blow on to the surface of these saline beds which were then exposed, or were washed into it, would be seen embedded and enclosed in the rock in exactly the same manner as the microfossils would be, under the conditions pictured

above by Professor Sahni adopting Christie's idea of sedimentary origin of the salt beds; the only difference being that in one case, the micro-organic remains get embedded in the soft sediments, while in the other, they got embedded in the soft and plastic salt; and then at a later period, or periods, during the Tertiary and post-Tertiary times, these saline beds together with these 'later-enclosed' organic remains have been involved in the intense earth movements which affected this area and have come to occupy the positions at great depths below the surface which they actually do now after those disturbances. Under these circumstances, we would today be seeing the saline beds in certain positions in the field, and it is possible to take out samples from undoubted *in situ* occurrences of the bed several hundreds of feet below the surface which would yield on proper treatment the microfossils found in them; but these fossils are evidently not the remains of life forms contemporaneous with the origin of the salt beds. These fossils are *in situ* only in the sense that they are in the place where they were first embedded; they are not *in situ* in the sense that they were included in the rock *at the time of its formation*. They are not 'derived' fossils as the term is ordinarily understood; they might be called "adventitious" fossils, and as such, having no value as age indicators of the containing rock.

It must however be pointed out that this manner in which organic remains may get enclosed in a rock long after its formation and stay there well preserved is very unusual and is possible only in the case of beds like those of the Saline Series on account of their special and unique properties of softness, solubility, and plasticity; and it is only in the case of such beds that any doubts can be raised regarding the value of the contained microfossils as age indicators of the containing bed. If this mode of inclusion of organic remains in the salt beds should be possible under these conditions in the Tertiary period, then it follows that even before the Tertiary period, or after it, whenever similar favourable conditions obtained in the area of the Salt Range, minute organic remains of the surrounding contemporaneous vegetation would similarly come to be enclosed within the salt. As a result of Mr. Gee's detailed mapping, it is now well known that there have been several breaks in sedimentation in the Salt Range area after the Cambrian period, represented by disconformities and unconformities in the stratigraphical succession; and every such gap would probably represent a period of time favourable for the inclusion of such 'adventitious' fossils. A more detailed examination of the beds of the Saline Series from different parts of the area for microfossils on the lines now adopted by Professor Sahni may reveal the occurrence of such remains of ages other than

the Tertiary,—some older, and others younger; and this is a point which further investigations must decide.

The one point, however, that still remains to be considered is the fact that the microfossils are found not only in the salt beds, but also in the associated dolomites and oil shales, which according to Prof. Sahni is most significant. This point will have to be tackled, and for doing so, it is most necessary to investigate the exact character of these dolomites and oil shales, with special reference to their lithological condition at the time of their origin and the changes if any, in their petrological character which they may have undergone subsequent to their first formation; and also to study them in greater detail in the field and determine their exact stratigraphical relationship with the Saline Series. Such a study may throw some more light on the problem and perhaps enable us to find either a possible explanation for the adventitious occurrence of the microfossils in these rocks or might serve to confirm the idea that these fossils are indigenous in these rocks which form an integral part of the Saline Series and thus dispel all doubts regarding their testimony as age indicators.

Thus it would appear that all the salt beds and the other associated formations of the Saline Series throughout the Salt Range area—both cis-Indus and trans-Indus, will have to be now thoroughly examined for microfossils; and when this is done, we will be in a position to find out whether the assemblage will be a 'consistent' one indicating an Eocene age for the entire Saline Series, or will turn out to be a 'mixed and mutually conflicting' assemblage of forms. In this connection it would also be worthwhile to study other similar saline beds in other parts of the world whose age it has been possible to fix more definitely on stratigraphical evidences, and examine them for microfossils if any, and their age indications.

If, however, we accept the testimony of the microfossils now discovered and conclude that the Punjab saline beds are Tertiary in age, then we are faced with the 'tectonic' aspect of the problem, and we are obliged to accept the occurrence of a major overthrust in the area, with all its structural and stratigraphical implications, to satisfactorily account for the succession as we now see it. The idea of the 'overthrust' is quite an old one, having been suggested so far back as 1902 by Koken and Noetling. It received some further support in the hands of Dr. Pascoe who in 1920 revived this idea and supported the view that "the salt marl and its accompaniments in the cis-Indus Salt Range are of Tertiary rather than of Cambrian or pre-Cambrian age"; but this view he now admits was "not based on any extensive geological re-examination of

the area.” We owe to Mr. Gee the most detailed mapping and intensive field work in the Salt Range area within recent years. As is well known, during the first few years of his work, Mr. Gee thought that all the evidence he had noticed, both stratigraphical and palaeontological, was in favour of the Tertiary age, and said so repeatedly; but as his own work progressed in the field, he discovered that all this evidence on which he was relying was ‘false’ and ‘misleading’, and that in the light of his further observations, the correct view was that the salt beds were really Cambrian in age. On the palaeontological side, Mr. Gee noticed the misleading character of the evidence when he found that the fossiliferous bands (containing foraminifera and other fossils) which he previously thought were truly part of the Saline Series, were really not *in situ* in the Salt marl, but were “either washed into the marl sequence in fairly recent times, or had been caught up in that sequence during the latest phase of earth movement in sub-Recent times”; and on the stratigraphical side, he was misled to think that the junction between the saline beds and the overlying formations was always of the nature of a ‘tectonic contact’. Later work revealed that in several places this contact was a ‘normal sedimentary’ one, with the result that the infra-Cambrian position of the Salt beds must be considered as truly normal in character and therefore indicating their correct age by their very position in the stratigraphical succession. Thus on the basis of Mr. Gee’s work, the case for the pre-Cambrian age of the Saline Series appears to be well established, particularly from the point of view of the field geologists. It is no doubt true that there are a few sections here and there where the junction between the saline beds and the overlying strata is not so normally sedimentary as Mr. Gee believes, but on the other hand, actually shows evidences of considerable disturbance; and having these cases in mind, it is possible to argue that this evidence based on the nature of the junction cannot be considered as clinching the issue. But as Mr. Gee says in his 1940 paper (wherein he first announced his abandonment of the Tertiary view) “If the Saline Series were in its normal stratigraphical position beneath the Palaeozoic beds, then at some place or other evidence of transition or of a normal sedimentary contact, or at least of the occurrence of rocks derived from the Saline Series and deposited within the basal Talchirs should be forthcoming. It was obvious that, if at even only one locality such evidence was indisputable then, in spite of a tectonic contact elsewhere, the idea of a large ‘primary’ overthrust must be abandoned and the pre-Purple Sandstone age of the Saline Series would be proved.” Accordingly, having actually found a few sections where the contact was clearly of the nature of a normal undisturbed sedimentary (though uncon-

formable) junction, he immediately accepted their testimony in support of the older age and assigned the salt beds to the pre-Cambrian. According to him, "the shearing and tectonic complications that were discernible (in several places) at the junction of the Saline Series and the overlying formations might quite likely be the result of intense earth movements that had caused the folding and repetition by reversed faulting and thrusting of the complete stratigraphical sequence during late Siwalik to sub-Recent times." It might, of course, be argued the other way about, and the question may be raised whether the 'normal sedimentary contact' appearance may not after all be more apparent than real, and that it is possible that even true 'overthrust junctions' might sometimes stimulate the appearance of "normal sedimentary" contacts, closer examination revealing that the apparent normality is altogether deceptive. This obviously raises a very vital issue in the present discussion, and it is a matter which the expert field geologists with intimate knowledge of tectonics must discuss and decide, with special reference to the Salt Range area.

At the present moment, there appears to be considerable force in the attitude taken up by Mr. Gee; and considering all the observations and arguments which he has put forward, along with those of others who are most familiar with the stratigraphical and other geological aspects of the Saline Series in the Salt Range and other similar problems connected with Salt deposits elsewhere, it would appear that the case for the pre-Cambrian age of the Punjab Saline Series (as distinct from the Saline Series of Kohat) is very strong; and the burden of proof in support of a younger age still rests on the palaeontologist, and it is for him now to make his evidences so 'convincing' that the field geologist will be forced to revise his notions of tectonics and accept the inescapable verdict of the fossils as inevitable and final. Professor Sahni's work constitutes the most serious attack on the problem from the palaeontological side; it has not only already stimulated considerable activity in the geological camp, but has also opened out a whole field of research including other possible 'independent' and 'neutral' lines of enquiry which are likely to throw more light on this perplexing problem. The controversy promises to become positively exciting; let us hope that at the end of it all, we will have a really final solution of this most intriguing and tantalising problem in Indian Geology

MICROFOSSILS FROM A KEROGEN SHALE OF THE SALINE SERIES IN THE KHEWRA GORGE, SALT RANGE

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(*With one Plate*)

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ABSTRACT

Some micro-remains are described from a thin layer of combustible kerogen shale interbedded with finely laminated sandy gypseous dolomite at Anderson's locality in the Khewra gorge. The material was at first prepared for microscopic examination by maceration in Schulze's fluid, but later a few samples of the shale were allowed to break up in water only, before being mounted. Slides prepared after this simple treatment with water revealed that the shale contained innumerable, very small, fusiform bodies made of calcareous matter. It is here thought that that these bodies have possibly been formed by a secondary infilling of diatoms by calcium carbonate. The other fossils recovered from the shale are a piece of well preserved insect chitin (discovered by Prof. Sahni) and a woody fragment showing simple pits. Neither of these fossils can be as ancient as the Cambrian, and there is no doubt whatever that they are indigenous to the shale.

INTRODUCTION

The material was collected by Prof. B. Sahni, F.R.S., during his visit to the Salt Range in October, 1945, and was kindly passed on to me for microfossil analysis. His own examination of a part of this material resulted in the discovery of an insect chitin showing prominent circular hair bases, with the hairs in many cases still intact (see photos. in Prof. Sahni's paper above). This chitin is being described in detail by Mr. M. S. Mani.

The shale (No. S.81) is described by Prof. Sahni as a "very thin black band interbedded with the sandy gypseous dolomite at R. van V. Anderson's locality in the Khewra gorge". According to him this band is only 2-3 inches wide, and in places it is even thinner. From this dolomite, a few metres below the horizon of the kerogen shale, Anderson had collected in 1924 some impressions of dicotyledonous leaves which were referred by Prof. R. W. Chaney to the

genus *Quercus* (Anderson, 1927). The shale is deep brown in colour and finely laminated as seen in sections cut across the bedding plane (photos. 1, 2). It is soft enough to be broken between the fingers. Heated, it burns with a smoky luminous flame giving off a smell of kerosene. Mr. C. P. Sood, Chemist to the Geology Section of this Department, who kindly analysed the shale for its volatile content, has found that it contains 52.40% of such matter. It is mostly carbonaceous in nature, as during the early stages of ignition the inner surface of the crucible was covered with a thick layer of soot. This percentage is obtained from analysis of only one sample; it is probable that the percentage will become higher if several samples collected from different spots in the bed are analysed.

The very compact and finely laminated character of the present rock excludes the possibility of its having been contaminated by extraneous matter through solution holes or cracks subsequently to the date of its deposition. Typical oil shales resist weathering (*Stutzer and Noé*, 1940, p. 236). Dr. A. Lahiri's section of the kerogen shale, Warchha B1 (1945, *photo.* 2) shows that the carbonised matter present in it lies along planes parallel to the planes of bedding. No foreign matter intruded subsequently to the deposition of the shale through cracks or solution cavities could assume such regular stratification within the matrix.

DESCRIPTION OF FOSSILS

1. *Wood*.—From a number of slides prepared by maceration of the shale in Schulze's mixture the only recognisable piece of wood obtained is shown in photo. 3. It is a small fragment of the same colour and texture as the pieces of kerogen shale among which it lies, though the part in which the pits are situated is more transparent than the rest. The form of the pits is simple; they are more or less oval in outline and arranged with their long axes parallel to each other. In the upper part of the photograph three pits are seen lying in a nearly straight row. The lowermost part of the specimen shows four more pits, two of which are preserved only in halves. It is not possible to say much as regards the affinities of the wood, except that the structure probably indicates an angiospermous character.

2. *Diatom-like bodies* (photos. 4-8).—These fusiform microscopic bodies are the most interesting and at the same time puzzling find from the Khewra shale. They occur in a very large number in all the slides prepared by breaking up the shale in water without the use of acid. That they are made of some calcareous substance is evident from the vigorous effervescence produced by the addition of a few drops of dilute hydrochloric acid to the powdered shale.

Subsequent examination of the shale so treated shows no trace of them. The calcareous nature of these bodies also explains their complete absence from the material macerated in the Schulze's solution. Not a single slide made of the macerated shale shows even one of these bodies, and one cannot but conclude that they were all dissolved out by the acid.

Dr. R. C. Misra, Lecturer in the Geology Section of this Department, who kindly examined these bodies under the petrological microscope, says: "The majority have a well defined oval or lens-like outline, but there are some with irregular shapes. On rotation of the polarizer the phenomenon of twinkling is clearly observed. The extinction angle is zero with respect to the length of the bodies. Bright polarization colours of high orders are seen. It appears that these bodies are microfossils which have been replaced by calcium carbonate". (*See Rogres and Kerr, 1942, Table III, p. 154.*)

The petrological test confirms the idea that calcium carbonate forms the substance of these bodies. In Canada balsam mounts they exhibit a sharp border, indicating a refractive index such as that of calcite. It is important now to make sure that these bodies which we consider as microfossils are not merely crystals. Dr. Lahiri (1944, *p. 654*; 1945, *pp. 330-331*) has observed minute crystals of calcite in samples of some oil shales from Kalabagh and Makrach. I do not at present know whether the crystals mentioned by him are of the same nature as the bodies here described, but Mr. S. R. Narayan Rao, Reader in Geology in this University, is also inclined to the view that, though the mineral of which the bodies are constituted is crystalline, probably calcite, *the individuals are not crystals*. It was for some time thought that they might have crystallized in the laboratory while the shale was being broken up in water. This has been proved to be wrong, for when a small piece of shale is powdered dry in a mortar without being allowed to come in contact with water, mounted in Canada balsam, and examined under the microscope it still shows the bodies in the same large number. These bodies do not also seem to be crystals which were formed inside the oil shale at some date subsequent to its consolidation, for it seems extremely improbable that a rock of such an impermeable nature would allow carbonates dissolved in atmospheric waters to percolate into its matrix and crystallize there.

The arguments against the crystal nature of these specimens are several: (1) their occurrence in a very large number in the same regular fusiform shape, without any wide variation of size, (2) the absence of any discernible cleavage planes, (3) the absence of faces and edges, and (4) the pronounced curvature of their outline on either side of the longer axis (see photos. 4-8). Though

curvature of crystal faces is known from certain causes, *e.g.*, that resulting from oscillatory combinations (calcite), that due to a succession of vicinal faces (gymsum), from some independent molecular condition producing curvature inside the luminae (diamond), the present specimens cannot be put under any such category. In all these cases the faces and their edges are clearly visible. It may be thought that these bodies are probably scalenohedra of calcite which have assumed their present shape due to the abrading action of water during the period of the deposition of the rock. It is difficult to imagine, however, that this process can result in such a remarkable regularity of shape and size in a large number of specimens.

With these difficulties confronting us in our attempt to explain away the present specimens as crystals, it might be well to consider the alternative that they are of organic origin and to imagine them as casts of diatoms resulting from the infiltration of a solution of calcium carbonate, or as diatoms whose siliceous walls have been replaced by a calcareous mineral. Calcite is known to occur as secondary infillings of plant spores or replacing algal structures (*Milner*, 1940, *p.* 419). According to *L. Cayeux* the silica of the frustules of the diatoms in the Cretaceous rocks of the Paris Basin has often been replaced by calcium carbonate (*Seward*, 1898, *p.* 153).

While the diatomaceous character of the specimens is itself in doubt it would be unwise to compare them except in the vaguest terms with any known species of that group. It may, however, be remarked that their shape is reminiscent of the *Navicula* type (*West and Fritsch*, 1927, *p.* 374, *Figs.* 157 *A* and *B*) which occurs widely distributed in fresh, brackish, and salt water, and which has also been found in the fossil state (*Hirmer*, 1927, *p.* 52, *Fig.* 32) in the Tertiary period.

CONCLUDING REMARKS

Age of the shale.—Whether the diatom-like bodies described above can throw any light on the age of the shale and thus of the Saline Series is debatable. Once, however, doubts regarding their diatom-nature are set at rest, they should be of considerable value as indicators of a post-Cambrian age. In fact there is no satisfactory evidence of the occurrence of diatoms in the Palaeozoic (*Fritsch*, 1935 *p.* 642), though some authors record them from the upper Silurian and Devonian (*Hirmer*, 1927, *p.* 44). *Seward* (1931, *p.* 426) says: "No undoubted examples of these algae have been found in rocks older than the early part of the Jurassic period; the family became cosmopolitan during the Tertiary period".

The woody fragment, with well defined pits, on the other hand, clearly points to a post-Cambrian age, for there can be no doubt that it belonged to a vascular plant fairly high up in the scale of evolution.

Alteration of the organic matter of the shale.—Though Mr. Sood's analysis reveals a fairly high carbonaceous content in the shale, the paucity of recognisable microfossils in it is rather surprising. This can only be explained on the view that most of the organic remains have become too badly disintegrated and chemically altered to reveal any structure.

A fairly reliable preliminary index of the richness of a given shale in organic matter is provided by its behaviour in the alkali after the maceration process has been completed. Normally, when we macerate in Schulze's solution a piece of shale rich in organic remains, we find that as soon as alkali is added to the macerated material the carbonised matter begins to dissolve, producing currents of dark liquid; and in a short time the whole of the supernatant solution becomes a deep brown to almost black in colour depending on the amount of soluble humic matter in the shale. When the present shale is macerated in a mixture of about 50% nitric acid (the strength normally used) and potassium chlorate for a week, treatment of the macerated material with alkali produces no such change. The humic matter, however, dissolves out in large quantities when concentrated acid is allowed to act on the shale for a fortnight. The residue washed and mounted is seen to consist of indubitable fragments of cuticles, but with no cellular structure visible.

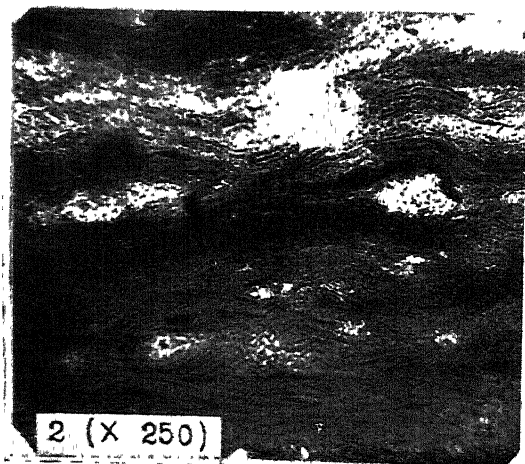
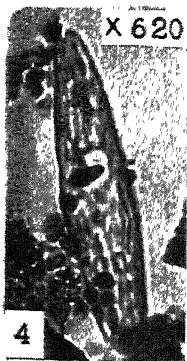
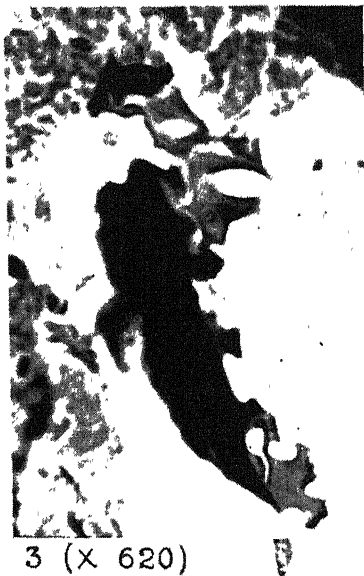
In cross sections the shale is seen as if it had been compacted from a mass of very fine strands (photos. 1, 2); it is possible that this appearance is the result of an advanced disintegration of woody tissues obliterating all traces of structure.

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*This paper has not been available to me.

R. V. Sitholey: *Microfossils from Kerogen Shales*



EXPLANATION OF THE PLATE

All the photographs are untouched.

1. Section of the oil shale (S81) across the bedding plane. X55.
2. Same section more highly magnified to show the thin strands of which the shale seems to be compacted. X250.
3. The solitary piece of wood found on macerating the shale with Schulze's reagent. X620.
- 4-8. Calcareous diatom-like bodies obtained from the shale after it has been allowed to break up in water. X 620.

NOTE ON THE AGE OF THE SALINE SERIES.

By

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(Received 26 December 1945)

I feel I am not well equipped to make comments upon the much-discussed problem of the age of the Saline Series of the Punjab as I have not personally visited any of the many excellent sections described by various investigators. At the same time, however, I am tempted to make some general observations on the broader aspects of the problem. The present Symposium has provided an opportunity for bringing the main differences in interpretation to the fore but the controversy still continues to swing between the Tertiary age of the Saline Series on the one hand and the Cambrian age on the other.

The occurrence of the Trans-Indus Tertiary salt so close to the supposed Cambrian salt of the Salt Range area is in itself quite intriguing. But it becomes more so if the salt deposits of Mandi State are also granted a Tertiary age. Then we have a separate block of Cambrian salt of the Salt Range area, so to speak, wedged in between the Tertiary salt of the Trans-Indus region in the west and the Tertiary salt of Mandi State towards the head of the Gulf in the north-east. This circumstance from broader geological considerations may not be improbable, but it would hardly seem to be likely. It would be somewhat curious that conditions favourable to deposition of salt bodies were obtaining in the Tertiary Gulf in the west and in the north-east but not in the intervening region comprising the Cis-Indus Salt Range area. It has been reported that salt and salt-water springs occur in Chamba State as well, but I have not had occasion to verify these reports. If these reports are true, it may be that Mandi salt has some stratigraphic continuity with the Chamba salt, in which case this extension of the Mandi salt brings it closer to the Salt Range.

Essentially, the controversy exists because of stratigraphic anomalies which have been differently interpreted by different observers. The problem has been subject to almost continuous examination and revision for several decades. Micropalaeontological evidence has only very recently come into the picture. So far we have a purely stratigraphic reconstruction of the structure of the Cis-Indus Salt Range area which has failed in its purpose, and it would

appear necessary, if it were possible, to seek some other evidence which might be helpful in the solution of the structural anomalies of the area under consideration. Micropalaeontology, as would appear from the recent investigations of Professor Sahni and his colleagues, provides a new approach to the problem, specially in an area where strata are more or less devoid of larger fossils. I would not, as Sir L. L. Fermor has done, place the stratigraphical and micropalaeontological evidences in opposite camps, strictly demarcated from each other. Unless each of these evidences is used to solve the difficulties of the other, it would hardly be possible to resolve the controversy.

Dr. Fermor has pointed out the possibility of infiltration of fossil materials into the salt but he admits at the same time that this would be possible if the conditions are suitable. There is nothing remarkable about such a possibility. The point is whether and to what extent these suitable conditions were obtaining and, if they were in existence, how far deep into the body of the salt and with how much uniformity this infiltration could take place. Professor Sahni (*Proc. Nation. Acad. Sci. Ind., Vol. 14, No.6, 1944, p. viii*) has made it clear that the "evidence for the fossiliferous nature of this series is too clear and widely distributed to admit of these fossils being 'derived' and not strictly *in situ* from the time the deposits were originally laid down." In addition the occurrence of similar fossils in the dolomite and bituminous oil-shale is evidence that cannot lightly be dismissed on the mere supposition of a *possible* subsequent infiltration.

The school of thought which advocates a Cambrian age for the Salt Range salt has not advanced any evidence to establish beyond doubt the existence of desiccation conditions in that period or of conditions under which the whole thickness of salt-marl could have been formed. Since the original view acknowledged a Cambrian age of the salt, and since after a period of doubt the salt could not be referred to the Tertiaries on account of certain structural anomalies, the swing back to the original view does not either explain away the difficulties of the problem or provide a solution for it. It has been stated (*Emmons: Principles of Economic Geology, 1940, p. 487*) that the volume of the salt precipitated from sea-water is less than 2 per cent of the water and that for 1,000 feet of salt to be deposited by precipitation over the floor of the ocean, it is necessary to assume a volume of sea water having the concentration of the ocean, equal to a depth of 50,000 feet over the basin. On the basis of this the formation of 1,500 feet of salt marl (*Wadia: Geology of India, and Krishnan: Geology of India and Burma*) would require a far deeper basin. Does such a Cambrian basin of this depth appear probable? Either definite desiccation conditions, therefore,

have to be established, or, the above depth of the Cambrian basin has to be proved and accepted. In contradistinction, the Tertiaries do provide evidences of land-locked bodies of water and of the existence of desiccation conditions under which salt deposits could have formed.

Dr. Lehner has made an excellent suggestion about the construction of sections on a broader base. If I might add to it, I would suggest that sections across all the salient regions from Mandi in the north-east to the Salt Range in the south-west should be made and that each section be correlated with the succeeding and preceding ones so as to form an idea of the structural variation along the whole of this tract. But with all this, I am inclined to feel that without the support of palaeontological evidence, the anomaly or anomalies are likely to remain unsolved.

GENERAL DISCUSSION

27th December, 1945.

In his opening address **Professor B. Sahni** expressed the thanks of the delegates to the authorities of Mewar State for their generous hospitality and for the excellent arrangements made for the scientific meetings. The subject of the discussion was still evoking keen interest, and several geologists abroad had again sent valuable written communications. Considering the long distances in India it was gratifying that geologists had gathered at Udaipur from places as far off as Baluchistan, Assam, Madras and Bangalore. Special thanks were offered to Mr. E. R. Gee for his previous evening's lecture, illustrated with coloured lantern slides, in which he had described some of the main features of Salt Range geology.

Mr. E. R. Gee (Nok-Kundi, Baluchistan) remarked :

"Professor Sahni has raised the following three points—(a) How could one be sure that the boulder and pebbles of gypsum met with in the basal Talchirs of the Daud Khel area were derived from the Punjab Saline series and not from some other source; (b) What new facts in favour of the Cambrian view have come to light as a result of the excursion of October, 1945; and (c) What were the reasons for my favouring the Tertiary view some years ago.

"Regarding (a), the gypsum boulder and pebbles in question are of exactly the same type as the massive gypsum (with marl) of the Punjab Saline series of that locality. They are of the same characteristic pink colour with thin intercalations of dark red and blue-green marl. The possibility of their having been derived from another source, such as the Salt Pseudomorph beds, was considered, but the latter sequence is not met with in this western part of the Salt Range. It appears extremely difficult not to regard the nearby Punjab Saline series as the source of the gypsum boulder and pebbles in the Talchirs.

"Regarding (b), except for the above-mentioned gypsum boulder etc., no new facts in favour of the Cambrian have been forthcoming; the excursion merely demonstrated further the evidence of the Talchir unconformity which is regarded as conclusive proof of the Cambrian (or pre-Cambrian) age of the Punjab Saline series. This evidence, namely, the sedimentary nature of the junction between the Talchirs and the dolomite (topmost stage of the Saline series) west of Ratta, and the occurrence of exactly similar dolomite below

the Purple Sandstones at Amb in the same area, was noted in the original survey. Apart from these Ratta-Chittidil sections, there are others in the western part of the Salt Range, *e.g.*, near Buri Khel and Pai Khel, where a similar sedimentary contact is observable. All of these are part of the same line of evidence.

"One further point demonstrated during the excursion was the fact that in those cases where definite thrusting involving the upper beds of the Saline Series obviously does occur, as in the section just west of Jalalpur, the basal beds of the overlying Purple Sandstone series are also appreciably disturbed. That being so, still greater disturbance would be expected had there been a 20-mile thrust between the Saline series and the Purple Sandstone, but instead one observed little or no sign of disturbance in the majority of the sections.

"Concerning (c) the Tertiary view was advocated mainly on the evidence of plant fragments found in clays and saline marl closely associated with the seams of rock salt, and of sand and grit bands containing Eocene foraminifera intercalated among the gypsum-dolomite beds. At that time, the middle-western parts of the Range where the sedimentary contact between the Talchirs and Saline series occurs had not been mapped in detail. Assuming the plant-fossils and foraminifera to be *in situ*, it was necessary to advocate a post-Middle Eocene—pre-Nimadric (Miocene) thrust, as described in my contribution to the 1944 Symposium (see pages 295-296). One would have to assume that the roots of the postulated overthrust had been obscured by subsequent, late Tertiary to sub-Recent displacements in which the Nimadric sequence was also involved. Further fieldwork showed that the plant-fragments, etc. could not be regarded as being *in situ* whilst, on the other hand, the new facts observed in the middle-western areas rendered the Tertiary view untenable.

"Concerning Professor Sahni's reference, in his opening address, to the fact that the opinion of geologists is divided whilst that of palaeobotanists is unanimously in favour of the Tertiary view, I would point out that, among those geologists who advocate a Tertiary age none, except Professor Sahni, has visited the critical sections of the middle-western areas and that all those geologists (excepting Professor Sahni) who have examined those critical sections are unanimously in favour of a Cambrian (or pre-Cambrian) age for the Saline Series. These geologists are all experienced and approached the subject with an open mind and they include Dr. Lehner who was well-versed in Alpine tectonics and thrust-structures. The great importance of the work done by Professor Sahni and other workers of Lucknow University, and also by Mr. Mani is, of course, realised but at the same time the stratigraphical

evidence against a Tertiary age appears to be quite definite. The contact between the Talchir conglomerates and the Saline series is comparable to that between the basal pebble-bed of the Neobolus Shales and the topmost Purple Sandstones where there is no question of the junction being other than sedimentary.

“Regarding Mr. Trivedi’s suggestion that the reddish colour of the basal Talchirs where they overlie the red Salt Marl may be due to subsequent staining by ferruginous material from the latter and need not necessarily indicate a derivation from the red marl during Talchir deposition, it is agreed that this possibility must be carefully considered though the obvious explanation—namely, admixture of a small quantity of red Salt Marl in the basal Talchirs at the time of deposition—appears to be the correct one.

“Referring briefly to the papers of certain other contributors, it may be pointed out that with reference to the contribution by Dr. Krishnan and Mr. Aiyengar, the Punjab Saline series never directly underlies the Salt Pseudomorph Shales, except possibly as a result of obvious faulting. The series either underlies the Maroon shales and flags of the lower part of the Purple Sandstone series or else follows directly below the unconformable Talchir Boulder Bed. As regards the structure and alignment of the Salt Range and adjoining areas being affected by wedges of Archaean rocks, it was agreed that this has occurred, as pointed out by me at the 1944 Symposium (see page 283) but such features in no way imply a regional thrust, and from that standpoint the Cambrian (or pre-Cambrian) view would meet the case satisfactorily.

“Regarding the question of the occurrence of the Saline series within the Eocene sequence of the Potwar area, it may be observed that—as described by Mr. Pinfold in his contribution and in a paper recently contributed to the National Institute of Sciences of India—apart from the evidence of the Eocene outcrops at the northern and southern edges of the Soan syncline, there are the data of a number of oil-wells, at Khaur, Dhulian and Joya Mair, all of which have penetrated into the Laki limestones without encountering salt deposits. There is, therefore, good evidence to conclude that the Saline series is absent from at least the greater part of the Potwar area. The paper from Mr. Anderson summarising his views on the problem is welcomed. As has been previously stated, thrust-structures in the Salt Range are admitted, but these do not necessitate a regional thrust. As regards the reported fossil dicotyledonous leaves found in the top gypsum-dolomite stage in the Khewra gorge, it may be mentioned that the material sent to the Geological Survey of

India for examination contained no recognisable macroscopic fossils. As regards Mr. Anderson's queries concerning the junction beds of the western part of the Range, where the Talchir Boulder-bed overlies the Saline Series with an unconformable sedimentary contact, it may be mentioned that the question of correlation of the strata involved has been very critically studied—it has, in fact, been one of the points to which particular attention has been given not only by myself but by all those who have visited the sections—and there is ample reason for regarding our conclusions as correct. Similarly, the question of the inclusion in the Talchirs of rock-fragments from the Saline Series has been considered (*see above* in the earlier part of this discussion), whilst the possibility of re-consolidation subsequent to low-angle thrusting has not been overlooked. The regularity of the overlying Talchir sequence over wide areas is, in fact, remarkable and incompatible with a tectonic junction.

“Dr. Lehner's further contribution is also welcomed and deserves greater consideration than has yet been possible in the short time available.

“Mr. Lamba's paper describing a recent bore-hole into the Lower Gypsum-Dolomite stage below the Khewra Salt Mine is of interest in again demonstrating the occurrence of petroleum in the Punjab Saline Series. His other contribution, correlating two shallow bore-holes put down at the foot of the gypsum hill at Khewra is, however, based on incorrect premises. From an examination of the cores, it is evident that not only was Eocene limestone encountered but also dolomite and glauconitic dolomitic sandstone which can, with reasonable certainty, be correlated with the Magnesian Sandstones. It appears that the holes passed through gypsum or gypseous clay into a sub-Recent conglomerate containing boulders of Eocene limestone and of Magnesian Sandstone. Such conglomerates occur as irregular bands caught up in the gypsum-marl beds of the locality in question. The evidence of the two bore-holes, therefore, in no way bears on the age of the Saline Series and, even supposing that a regular bed of Eocene limestone had been met with in depth, it would—as Mr. Pinfold has pointed out in his contribution—not have been surprising, for it is probable that, at a number of places now hidden by alluvium, the Saline Series has been thrust southwards across Eocene rocks in the same way as it has been sheared across Siwalik strata at Jalalpur to the east.

“In conclusion, I would like to thank Professor Sahni for arranging this second Symposium and would again request those who have not examined the critical sections of the Warcha-Sakesar area to do so as soon as the opportunity

permits. Should circumstances allow, I will be glad to accompany them. Possibly, by studying the sections on the spot, we may be able to discern the true significance of the plant and animal remains that have been proved to occur in the various members of the Saline series."

Mr. Gee was then requested to present his paper, entitled "Further note on the Age of the Saline Series of the Punjab and of Kohat" (pp. 95-116). He emphasised that if the Saline Series was Tertiary there must have been an enormous thrust from North to South (or it may have been from South to North) of at least 20 miles, and the whole of the Potwar area must have moved as a single sheet. He admitted that thrust movements had taken place but believed that they were of relatively local extent. *If there had been a regional thrust then some indication of it should be visible at all places* and there should not have been left anywhere a junction which was devoid of all external evidence of disturbance. He was quite definite that the contact of the Talchir Boulder Bed with the Saline Series near Ratta was an undisturbed sedimentary junction and that the Saline Series here must therefore be pre-Talchir. As regards the "sheared" Talchir boulders Mr. Gee now agreed that the fractures might quite possibly have been due to the causes suggested by Professor Sahni (*e.g.*, frost action) and not due to a thrust movement. The relatively young appearance of the rocks of the Saline Series was admitted but this fact alone was of no real consequence. Criticising the fossil evidence, Mr. Gee enquired whether the microfossils in the Saline Series could not possibly represent a Cambrian flora. Referring to the chitinous remains prepared by Professor Sahni from the oil shale (S 81) in the Khewra gorge (Sahni 1946; Mani 1946 pp. 43-56) he questioned their insect affinities, and asked why they might not have belonged to a trilobite. He agreed that it was difficult to assert that these fossils had been blown into the shale after it had been formed, but he was sceptic about their affinities and geological age.

Explaining his earlier stand in favour of the Tertiary view Mr. Gee stated that he had based it upon evidences of shearing along the now disputed plane of junction; certain plant fragments were also previously thought to be *in situ* in the Saline Series but he no longer considered them to be indigenous to the beds in which they were found. Moreover, at that time he had not yet seen the critical sections in the Dhodha Wahan which he regarded as decisive against the idea of a regional thrust.

Sir C. V. Raman (Bangalore) suggested that seismic methods might be tried at selected localities for detecting underground deposits of rocksalt in the

Salt Range and Potwar Plateau." He referred to the work of Joffe on the remarkable behaviour of rocksalt, which would enable the overlying strata to glide as if they were "skating" over the rocksalt.

Dr. M. S. Krishnan (Madras) thanked Mr. Gee for his valuable paper, based upon long field experience. Reading his joint paper with Mr. N. K. N. Aiyengar of the Geological Survey of India, Dr. Krishnan said that although he had not himself visited the Salt Range, his co-author Mr. Aiyengar was familiar with the area, and they felt they would not be unjustified in offering some general observations on the tectonic features. According to these authors the thrust phenomena in the Salt Range might be explained with the help of Wegener's drift theory. With a resistant southern block having a number of wedges along its front edge a single northward thrusting movement could account for the festoon-like trend of the strata, which had swung round the wedges. There were probably three periods of major movement in the Tertiary: during the Upper Eocene, the Miocene, and the Pliocene; and it was to be expected that each of these would be recorded in the Salt Range structure.

Dr. K. R. Ramanathan (Poona), referring to Dr. Krishnan's remarks, suggested that recorded data concerning deep-focus earthquakes might have some relevance to the observed facts. Seismic records taken since about the year 1920 showed that near Chitral ($36^{\circ} 5' N$, $65^{\circ} E$) about ten or twelve deep-seated earthquakes occurred every year at depths between 200 and 230 kilometres.

Professor Sahni, welcoming the above idea, and the paper read by Dr. Krishnan, drew attention to a suggestion he had himself made at Hyderabad in 1937 ("*Wegener's theory of continental drift in the light of palaeobotanical evidence*"). *Journ. Ind. Bot. Soc.*, Vol. 15 pp. 319-332; see also *General discussion on Wegener's Theory* in *Proc. 24th Ind. Sci. Congress, Hyderabad, Jan. 1937* p. 505). While pointing on that occasion to the pivotal significance of the Kashmir and Assam promontories of Gondwanaland, he had hoped it might some day be possible to detect the presumed nut-cracker-like movements round these wedges by actual observations of meridia in the regions of Afghanistan and Eastern Burma.

Mr. M. S. Mani (Agra) next read his article on "Fossil arthropods from the Saline Series" (pp. 43-56). These microfossils had been prepared by Professor Sahni, Mr. Trivedi and Mr. Lakhanpal from authentic rock-samples specially selected for examination. Apart from describing the various chitinous remains and discussing their affinities, Mr. Mani gave a brief

account of the evolution of the Chironomidae, which appear to have become differentiated in the Early Tertiaries or Late Cretaceous.

Mr. Gee welcomed Mr. Mani's paper, but remarked that the palaeontological evidence for the Eocene was unreliable. Even admitting that the microfossils were really *in situ*, it was not certain that the chitinous fragments from the Saline Series represented parts of insects, for several Palaeozoic groups like the brachiopods, trilobites, etc.; also possessed chitinous structures. He thought, therefore, that the microfossils might possibly belong to some Cambrian rather than to a Tertiary fauna.

Professor Sahni thanked Mr. Mani for his painstaking work on these chitinous fragments, most of which would otherwise have passed unnoticed, with the result that their corroborative evidence for the relatively young age of the Saline Series would have been overlooked. He remarked, however, that while he was himself convinced of the post-Cambrian case, in order to prove that case it was not quite enough to show that the microfossils in the Salt and Marl belonged to groups which did not exist before the Tertiary: it had been objected by Mr. Pinfold that they might be remains of species now existing which had become incorporated into these soluble rocks. If Mr. Mani could show that the *Chironomus* was an *extinct* form, the evidence of this fossil would be very difficult to refute. Professor Sahni regretted that there was no published systematic work describing the microscopic features of insect chitins on the lines of what we have for plant cuticles of some living as well as extinct groups. It was to be hoped that entomologists would be able to evolve a rational classification of living insects based upon the micro-structure of their chitinous coats. It would obviously be a great asset if such a scheme of classification was found to run parallel with that based upon macroscopic features. The task was bound to be a big one, but it would be of great use to the palaeontologist who could then identify fossil fragments by matching them with modern insect chitins.

Mr. Mani, replying to Mr. Gee, explained why none of the chitinous fragments could be referred to trilobites. Trilobites were marine organisms devoid of sensory setae, which the insects, being land forms, had developed at their nerve-endings. Referring specially to the chitinous membranes from the Khewra oil shale (S. 81) he said that they could not possibly have belonged to a trilobite because they were studded with sensory setae. He said:

"As is well known, the Cambrian Arthropods were exclusively marine forms like the Trilobita, Phyllocarida, Phyllopoda, Merostomata, etc. The

first undoubted air-breathing terrestrial Arthropoda, *viz.*, the Scorpiones, did not appear till the Silurian, while the insects arose from the now diminishing Trilobite stock during the Lower Carboniferous. Chitinous sensory surface-structures like the setae, spines, sculptures, etc., of the insects differ essentially from those of the marine Cambrian Arthropods. Moreover, the chitinous parts of the other Palaeozoic animals, like the Brachiopods, can never be confused with those of the terrestrial Arthropods.

“Although the microfossils from the Saline Series are mostly too fragmentary to be referred to genera or species, it is possible to easily recognise in them undoubted parts of the exoskeleton of insects, for example, segments of legs, antennae, etc. In many cases specialists will have no difficulty in placing these fragments in several of the well known orders or families. I would here draw attention to the tarsal segment (Figs. 6, 8 in my paper) found in a compact, finely laminated, grey dolomite within the lower part of the Saline Series near Warchha. I consider this tarsal segment to have belonged most probably to a Chironomid fly, which is certainly not a Cambrian Arthropod. Then there is the almost complete specimen of another Chironomid fly from the Salt Marl at Warchha. Even if some of the material is generically indeterminable, there is not the least doubt about the post-Cambrian nature of the fossils. The microfossils are in many cases insects with strong Cainozoic facies.

“Further, unmistakable parts of terrestrial Acarina (mites) have also been found in the Oil Shales of the Saline Series. It is common knowledge that the Acarina existed nowhere during the Cambrian, but are abundant as Tertiary fossils.

“Finally, I might also point out that even with such fragmentary material at our disposal, among the microfossils so far examined we have seen no mixing up of Cretaceous or Post-Cretaceous Arthropods with, for example, a Cambrian fossil. The evidence of microfossil animal remains consistently points to a Post-Cretaceous age. This fact, I think, is of considerable importance in deciding between such wide alternatives as the Cambrian and the Post-Cretaceous.”

“Professor Sahní has raised the important question as to whether there is clear evidence that any of the arthropod remains belong to species now extinct: if there is no such evidence they might be recent or sub-recent remains incorporated in the rocks since the date of their deposition. In view of the fact that most of the microfossil remains cannot be referred to genera or species,

it is not always possible to know whether we are dealing with extinct forms or not. The absence of specifically identifiable fossils is rather unfortunate. The Orthorrhaphous Nematocerous Dipterous fly, *Chironomus primitivus* Mani is, however, an exception. The almost complete specimen of this extinct Tertiary fly at first sight looked so modern that I originally mistook it for a Recent species.

“Recent species of *Chironomus* are generally separated by the proportions of the palpal and antennal segments, the male genitalia and venational characters. In the Warchha material, however, the antennae are missing and the genitalia and wings are damaged. Specific recognition naturally presented certain difficulties. Careful comparisons of the proportions of the thoracic sclerites of the Warchha fossil with those of a large series of Recent known and unknown species in the collections of the Imperial Entomologist, New Delhi, showed the fossil specimen to be quite distinct from any Recent form. Pleistocene species of insects are usually either identical with or morphologically extremely closely related to Recent species, while *Chironomus primitivus* is easily distinguished from such material. Evidence is therefore against a Pleistocene age for the specimen. Since we already know that the Chironomids arose during the late Cretaceous, the Warchha species could not have in any case been much older. This fact, as I have already pointed out, is significant, since all the other chitinous fragments from the Saline Series belong to groups which did not exist before the early Tertiary or perhaps the late Cretaceous”.

Dr. R. V. Sitholey (Lucknow) next presented the results of his detailed examination of the oil shale (S. 81), closely interbedded with the finely laminated gypseous sandy dolomite within the Upper Saline Series at the head of the Khewra gorge, near Mr. Anderson's *Quercus* locality. He described the behaviour of the rock under treatment (a) with alkali and (b) in distilled water alone; and gave a brief account of the microfossils recovered. These included a dark chocolate-brown fragment of pitted wood, of the same colour as the matrix and intimately mixed up with it. This fossil, like the chitinous membrane studded with setae, prepared by Professor Sahni from the same rock, was of great importance, for in no way could it be argued that the organic matter in this oil shale, which was present to the extent of at least 50%, was of extraneous origin. Neither the wood nor the chitin could possibly be of so ancient a date as Cambrian.

A fragment of Mr. Anderson's original material, kindly supplied by Dr. Crookshank, had also been now closely examined. In some slides prepared

by Professor Sahni, Dr. Sitholey had discovered two or three shreds of woody tissue.

Mr. B. S. Trivedi (Lucknow) then gave a brief account of his comprehensive work on "Microfossils from the Saline Series", covering a period of over two years. The fossils prepared from the different types of rocks had been classified and a summary of the data tabulated in a chart which showed at a glance the nature and volume of the fossil material recovered from the rocks, which included oil shales and dolomites collected by Mr. Gee and his colleagues of the Cambrian school.

Mr. R. N. Lakhanpal (Lucknow) followed with his paper on microfossils from core-samples recovered from two borings put down at Khewra.

He described shreds of carbonised and non-carbonised woody tissues, hairs, fibres and animal chitins from Salt Marl and dolomites at depths of 110, 117, 125, 143, 145, 149 and 229 feet below the floor of Chamber 10 in the South Pharwala seam in the Mayo Salt Mine. From an exploratory drift in the Bhandar Kas, near Khewra, he described further microfossils of post-Cambrian forms found in samples of rocksalt, kallar and dolomite.

Professor C. Mahadevan (Andhra University, Waltair, formerly of Hyderabad) observed that although he had not been able to pay a visit to the Salt Range yet he felt he could express an opinion in the light of the published data and of the discussion to which he had listened with much interest. He said that Dr. A. M. Heron (Hyderabad), a former Director of the Geological Survey of India, who had seen the area, was convinced of the Tertiary age of the Saline Series. To rely upon a "critical section", Professor Mahadevan observed, was a dangerous thing. He continued:

"The age of the Saline Series in the Punjab has been a subject of controversy amongst geologists almost since the area came under the notice of the Geological Survey of India. The field geologist attempts to construct a coherent story from fragments of evidence with its inherent limitations. The Salt Range is a region of great tectonic disturbance and even the most careful and conscientious work, such as that put forth in recent years by the officers of the Geological Survey, need not claim infallibility in view of the complexity of the tectonics of the area. Even with regard to much simpler structures in peninsular India and elsewhere, field geologists could not agree to a uniform conclusion with regard to the stratigraphic sequences or the geological history of the several formations. As examples, we may refer to the yet unsettled

problem of the age of the Palnads—a controversy started by two eminent geologists (Bruce Foote and King) from their actual field work in the sixties and seventies of the last century in the Purana rocks of Madras Presidency. The long drawn controversy with regard to the igneous or sedimentary origin of the Dharwars of South India and elsewhere, of the origin of the charnockites, of the exact stratigraphic position of the Kaladgis and the Pakhals, of the age of the Aravalis, of the correlation and stratigraphy of the formations in Chota Nagpur (amongst many others) indicated how persons engaged in the study of the same formations can entertain different views with regard to their age, origin and sequence. In a highly complicated area like the Salt Range, conclusions regarding geological age are naturally divergent.

“The very fact that Mr. Gee, who carried out a systematic survey of the Salt Range, had to change his views on the age of the Saline Series from Cambrian to Tertiary and back to Cambrian is indicative of the difficulties confronting field geologists in the area. Mr. Gee, on what appears to be very sound geological field evidence, advanced coherent arguments at the Indian Science Congress in 1935 and in later publications to prove a Tertiary age for the Saline Series. His later work, specially towards 1940, however, seems to point out a Cambrian age for the Saline Series.

“In support of the Cambrian view, the evidence of ‘critical sections’ has recently been emphasised and it has been claimed that the sedimentary junction in certain places between the Saline Series and the Talchir Boulder bed is suggestive that the Saline Series are in their normal position of deposition. It is a common experience of field geologists working in sedimentary formations that there could be errors of inference about such ‘sedimentary junctions’. If there had been no evidence of overthrusts at all in the whole region, and if this ‘sedimentary junction’ was universal, then, certainly this observation is entitled to acceptance. Actually, there is adequate field evidence to suggest overthrusts and nappe, contradicting the evidence supplied by some of the sections of a ‘sedimentary junction’.

“In such circumstances, we have to seek some internal evidence to arrive at an acceptable conclusion. During the last two years, Professor Sahni and his co-workers and more recently Mr. Mani of Agra University have examined microfossils prepared from rocks carefully collected not only by Professor Sahni but by Mr. Gee and others. Professor Sahni had, besides, the advantage of visiting the area and studying the field evidence. From a study

of the microfossils, the Lucknow school as well as Mr. Mani of the Agra University have shown conclusively that the Saline Series cannot be Cambrian or pre-Cambrian but must be much younger. The microfossils have not only been found in the Salt but have also been obtained from oil shales and dolomites associated with the salt marl. Even geologists strongly inclined to the Cambrian view of the Saline Series are ready to accept that it is difficult to account for these fossils to be introduced by any known mechanism into such impervious bedded formations as oil shales and dolomites. The palaeobotanical and palaeontological evidence, unlike the field evidence, is unanimous in pointing to a post-Cambrian age for the Saline Series. It is no disparagement to the excellent and most detailed and careful mapping carried out by Mr. Gee in this area, if it is suggested that in regions of such tectonic disturbance there is room for difference of opinion with regard to inferences about the sequence of the formations. The internal evidence afforded by the fossils which have been examined most critically by Professor Sahni and his co-workers as well as Mr. Mani of Agra is entitled to be accepted as proving definitely the age of the Saline Series as being Tertiary.

"The fact that there is more or less unanimity of field evidence in giving the Tertiary age to the Kohat Salt across the Indus, not so far away from the Saline Series, is an additional point in support of our surmise as to the Tertiary age of the Punjab Saline Series. Some of the contributors have tried to cite the analogy of the Persian Salt Deposits to stress the possibility of a Cambrian age for the Salt in the Salt Range; it is more likely that two contiguous deposits were formed under identical conditions than two greatly separated ones."

28th December, 1945.

Mr. J. Coates (Digboi) said that, as he had not himself done any original work on this problem, he had not submitted a paper, but that he was glad to take part in the discussion and answer the question of what personal opinion he had formed after seeing the field evidence once more and considering the other data presented.

(i) It seemed to him that in this problem there were two really primary (and apparently conflicting) lines of evidence; on the one hand the field evidence for stratigraphic continuity between the Saline Series and the acknowledged Cambrian beds, and on the other hand the botanical evidence which indicated that the included fossils were of much later date; beyond these data, there were many secondary but often quite striking lines of indirect or circumstantial

evidence which, had there been no conflicting primary evidence, could probably have been accepted as sufficient for reaching a practical decision, but whose validity must now remain undecided until the primary conflict is resolved.

(ii) It appeared that during the past year each of the primary lines of evidence had become strengthened; on the field geological side, no geologist who examined on the ground Mr. Gee's key sections (even in the most critical frame of mind) could remain unconvinced of the strength of the direct evidence for a pre-Cambrian age for the Saline Series; on the other hand the proliferation of the botanical evidence, and the finding of remains so widely distributed in the Saline Series (including the oil shales where it is very hard to imagine that they could be other than *in situ*), made it equally hard to accept anything but a post-Cambrian correlation.

(iii) In these circumstances one must be very cautious in drawing deductions from the secondary or circumstantial evidence, though this may legitimately be used to give a preference in working hypotheses or to suggest further lines of investigation. For example, one can plainly see in the Salt Range many places where contamination of the Salt Marl by surface material has actually occurred (*e.g.*, in the Warchha mine tunnel); but it does not necessarily follow that this mechanism should be held responsible for disseminating all the remains now found in the Salt. Similarly it is true that there are many places where the Purple Sandstone or the Gypsum-Dolomite series, being involved in local faulting, show the naturally expected disturbance due to this fact; but one could not with certainty conclude that they must always show such disturbance on faulting, and use the absence of major disturbance as a positive proof of the absence of major faulting.

(iv) Nevertheless the primary field evidence seemed to the speaker so strongly in favour of a pre-Cambrian age, and so many lines of secondary evidence seemed corroborative, that he felt forced to adopt this as the natural working hypothesis, and to consider that the solution of the problem now lies in finding out how post-Cambrian remains can have become so intimately incorporated into pre-Cambrian beds.

(v) It is hard at this stage to make constructive suggestions that have not already been put forward, and it may be that the age-determinations on the Khewra Trap, now awaited, will give a final answer. It might, however, be suggested that it would be helpful to have a fuller background of knowledge of what palaeobotanical remains would normally be expected in (a) Eocene and (b) pre-Cambrian beds in this region; in this connection the speaker recalled

that there are widespread records of carbonaceous remains in Cambrian and pre-Cambrian beds in India, and suggested that it might be useful to examine samples from, e.g., the Bijaigarh Shales of the Kaimur Series of the Vindhyan system from which even lenticles of coal are reported.

Professor Sahni welcomed Mr. Coates's concise and balanced statement, which showed that he took up the pre-Cambrian view only as a working hypothesis, in view of the field evidence from Mr. Gee's key sections. Two significant facts emerged from the statement. In the first place, when requested to be more precise and specific concerning the supposed contaminations in the oil shales (hitherto alleged only in general statements) Mr. Coates admitted it was impossible to show that any particular fossils out of the many post-Cambrian remains which had been described from these rocks were anything but indigenous to them. Secondly, Mr. Coates agreed that, while at many places the disputed junction of the Saline Series with the overlying Palaeozoic rocks was visibly disturbed due to faulting, *one cannot expect that such disturbance must be visible at all places where faulting has occurred, and use the absence of major disturbance as a positive proof of the absence of major faulting.* On this second point Mr. Coates clearly differed from Mr. Gee who claimed (First Symposium 1945 p. 327; see also above) that any major thrust movement must show visible signs of disturbance *in all the sections where the junction is exposed.*

Dr. R. V. Sitholey remarked :

"Mr. Coates has pointed out that in several places in the Salt Range contamination of the salt-marl by surface material is in evidence, but he admits that the mechanism there should not be held responsible for disseminating all the organic remains now found in the different members of the Saline Series, including not only salt and marl but dolomites and oil shales. Can Mr. Coates or Mr. Gee throw light upon the exact mechanism by which extraneous plant and animal remains could in their opinion have penetrated deep into the salt and marl, or even superficially into the oil-shale? Rain could only carry such fragments into isolated pockets and cracks in the salt and marl, but could scarcely account for their distribution through the body of the rock, as shown by the presence of the fossils in each and every sample of the salt and of the marl examined in the laboratory. Further, the way in which rain could generally be expected to work was to wash the exposed surface. This would tend rather to remove any contaminating material attached to the surface than to anchor it to that surface. Much less could it force it deeper into the matrix.

"In the case of the oil shales, neither wind nor rain could be of the slightest use in carrying microfragments into the body of the rock. Only a complete dissolution and re-sedimentation of the oil-shale would admit of contamination, but I understand that neither Mr. Gee nor Mr. Coates claim that this has actually been the case."

Mr. Coates ultimately agreed that he could not advance any satisfactory explanation of the processes by which any foreign organic remains could have penetrated the rocks, particularly the oil shales, where the microfossils could scarcely be regarded as other than original.

Conclusion.

Summing up the discussion **Professor Sahni** remarked: "This second Symposium in several ways marks an advance over the position as we had left it at Poona. For one thing, it has afforded us an opportunity to speak with a closer knowledge of the ground. The joint excursion of October 1945 (apart from its pleasant associations for which I am specially grateful to Messrs. Gee, Coates and Pinfold) has not only cleared up obscure points that needed examination on the spot, but has also provided fresh material from critical localities, the investigation of which has broadened the basis of the evidence in a significant manner. It will be convenient to review rapidly the extent and the manner in which it has been possible to meet the suggestions made at Poona.

"The result of radio-active analysis of the Khewra Trap is still awaited, and the recent excursion has revealed no suitable sections for magnetic determinations. But in other directions considerable progress has been made.

"(A) The **fossil evidence** is now more convincing than ever:

"(i) It is true, no macrofossils have yet been discovered; but in a fragment of Mr. Anderson's original material several microfragments of wood have been found by Dr. Sitholey.

"(ii) Microfossils have been found in several further samples of dolomites and oil shales collected from two critical sections in the Dhodha Wahan, one locality in the Fatehpur Maira gorge, one in the Khewra gorge and one near Jalalpur. The oil shales in the Fatehpur Maira gorge are particularly rich in the remains of woody plants and insects.

"(iii) From core-samples of dolomite and salt marl at depths of 110, 117, 125, 143, 145, 149 and 229 feet below the floor of Chamber 10 in the South Pharwala seam at Khewra, which itself is 525 feet below the surface, and 3,300 feet from the mine mouth, Mr. Lakhanpal has prepared microfossils essentially of the same general type as in the other rocks of the Saline Series.

“(iv) Mr. Trivedi has now furnished a voluminous record of microfossils of the same general character from many localities and horizons in the Series. In their affinities, and hence in their geological significance, the organic remains from the dolomites and oil shales do not differ from those found in the rocksalt and marl. The preponderance of angiosperms and the presence of gymnosperms and insects completely rules out a Cambrian or Precambrian age.

“(v) As a check against the contamination theories of Sir Cyril Fox and Dr. Lehner numerous test samples of known Palaeozoic age have been examined at Lucknow, both before and since the Poona meeting. These samples came from two localities in the Lower Gondwanas of Australia, from two horizons in the Dwyka tillite at Vereeniging (South Africa); from at least six localities in the Lower Gondwanas of India; from the Purple Sandstone near Khewra; and lastly from the Lower Tal beds in the Himalayas. The results of these tests uniformly support the conclusion that the fossils described from the Saline Series are not of exotic origin but must be regarded as strictly indigenous.

“(vi) Sir Cyril Fox and Sir Lewis Fermor, while criticising this conclusion, have avoided all reference to the fossils in the dolomites and oil shales which are of crucial importance. In view of the testimony of these fossils it is unnecessary to insist upon the evidence of the fossils in the rock-salt and marl, though this evidence is in line with that from the oil shales, and cannot lightly be explained away.

“(vii) Dr. Lehner's micro-crack theory is not supported by any specific facts. General statements apart, no one has yet claimed that even one of the fossils described from the dolomites and oil shales is demonstrably of extraneous origin. Messrs. Gee and Coates now accept the fossils as indigenous; but Mr. Gee's suggestion that these angiosperms, gymnosperms and insects may represent a highly evolved flora and fauna of Early Cambrian age is a negation of some of the fundamentals of palaeontology.

“(viii) Mr. Pinfold objects that the microfossils in the Saline Series are extraneous on the ground that they are not completely mineralised. It would be unfair to blame him for lack of familiarity with modern palaeontological microtechniques, which obviously need to be brought more prominently to the notice of geologists. Among palaeobotanists it is now common knowledge that flexible plant cuticles, spores and woody tissues (representing the un-mineralised organic residues of fossil plants) can be easily prepared out of

rocks of Mesozoic and even Palaeozoic age, and that they can be stained as vividly as modern plant fragments. Similarly, thin sections of even silicified plant tissues will often take up stains like safranin and gentian violet, showing that the whole of the organic matter of the cell walls has not been replaced by silica. In fact it is these unmineralised organic residues in the cell walls that make it possible to etch the cut surfaces of petrified plants and prepare "peel sections" from them. The technique of preparing anthracograms from thin sections of fossil plants also depends upon the same principle.

"(ix) Dr. Lehner has made ingenious attempts to show how exotic rocks containing microfossils of younger age might have been enveloped and invisibly assimilated into the Saline Series. So far as we know, these hypotheses have not been accepted by any of his colleagues of the Cambrian school. It is inconceivable that any foreign rocks so enveloped, even by so plastic a substance as rocksalt, could have become so completely digested by the enveloping strata as to lose all sign of their identity. Obviously, such a process would have completely obliterated the original stratification, and the present stratification of the dolomites and oil shales would have to be regarded as a new feature, acquired after the Saline Series had assimilated the foreign rocks. That the whole idea is fantastic will be clear from a single section, say, that in the Khewra gorge, where even a bed of volcanic lava, with its vesicular layer at the top, still lies closely interbedded within a series of finely laminated dolomites and oil shales.

"(x) From the Khewra gorge, the Warchha gorge and near Chitidil in the Dhodha Wahan, rock-samples taken from below upwards in the Salt Range sequence have been examined, as suggested by Mr. Coates, in order to see where a significant change in the character of the flora or fauna appears. In all three localities it was found that while angiosperm and insect remains always occur in the Saline Series rocks (that is, below the suspected thrust-plane) there is no trace of these groups in any of the samples taken from the overlying Palaeozoic beds, respectively the Purple Sandstone, the Lower Gondwana shales within the Productus Limestone, and the Talchir shales in the Talchir Boulder Bed. *The plane of contact above the Saline Series everywhere marks a sharp palaeontological break, thoroughly consistent with the overthrust idea.*

"(xi) The thick series of rocks forming the Tertiary oil-bearing system in Assam, which was previously thought to be practically unfossiliferous, is actually teeming with microfossils, which have been discovered in thousands. Preliminary work has shown that tiny samples of rock only

2 ounces (56.7 gms.) in weight taken from the different broad horizons, Barail, Surma, Tipam etc., can now be correlated solely on their contained microfossils. This would not have been possible if there were any considerable admixture of extraneous material. There is no doubt that close correlation can be achieved with more intensive work based upon samples taken from closer intervals both in depth and in horizontal extent.

“(xii) Mr. Gee’s statement that ‘no evidence of animal remains within the oil shales has been met with’, evidently refers only to macrofossils. The microfossils described and figured from these shales by Messrs. Trivedi, Mani and Lakhanpal and by myself are on the table, open to inspection, along with the rocks from which they were prepared.

“So much for the fossil evidence.

“(B) Turning now to the **field evidence**, this has also been more closely examined, in Mr. Gee’s critical sections as well as elsewhere. And, as we have seen, this closer enquiry, in the light of wider experience, has also yielded significant results.

“At one time it appeared as if the field evidence was directly opposed to the internal testimony of the fossils, and the impression was created that we were ranged in two opposite camps, with irreconcilable views. It was even suggested that perhaps we had an insoluble problem before us. But as I said last year, ‘Between the testimony of the rocks and the testimony of the fossils there can be no real conflict. If the two do not seem to agree there must be a mistake somewhere’ (1946 p. xxviii). The mistake, I feel convinced, has now been confirmed. *The fossil evidence stands unshaken: the mistake lies in the reading of the field evidence on the part of those who uphold the Cambrian view.*

“*The crux here is Mr. Gee’s insistence that in a regional thrust every single section where the junction is exposed must show evident signs of thrusting.* Here, I have no doubt, Mr. Gee is treading on dangerous ground, for we now know of too many parallel instances of a similarly deceptive kind in the Alps, in the N. W. Highlands of Scotland, in Scandinavia, in China and even in the Himalayas. Not being myself in any sense a field geologist I can only cite these instances on the authority of colleagues abroad, and in India, whose experience in tectonic problems is worthy of respect. We are all full of admiration for Mr. Gee’s work in mapping such a large and difficult area, which is of interest to geologists all over the world. But for the very reason that Salt Range geology is a subject of interest to such a wide circle of geologists it is important that our evidence should be considered in a synthetic context, in the

light of world experience of stratigraphical junctions. Viewed in this light the value of Mr. Gee's work would be greatly enhanced if he were to adopt a more elastic attitude in the interpretation of those sections where the Saline Series appears to form a normal sedimentary junction with the overlying Palaeozoic rocks.

"I cannot help concluding these remarks with a reference to the penetrating genius of Koken and Noetling who, after only a few days of field work in this intriguing area, and with no fossils to guide them, arrived at a result which at the time must have appeared revolutionary, but which after a period of over forty years has received such striking confirmation through the application of modern microfossil technique. It is legitimate to express the hope that these methods may in years to come find application in further problems of structural geology."

THE SIGNIFICANCE OF THRUST STRUCTURE OF THE SALT RANGE.

By

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(With two figures)

(Received 16 January 1946)

By courtesy of the President, I have been privileged to see the papers presented before the second Salt Symposium. Having done no field work in the Salt Range area since 1931 and having said my say on my previous work in the north-eastern part of the Salt Range during 1928-30, at the last Poona meeting of the Symposium, I had no wish to enter the list again except to propose an adjournment of the debate into which the subject of the age of the salt has drifted. Very few new facts,* that were not previously discussed, have been brought forward in the second batch of papers; and it appears the controversy has entered the stage where it cannot see the wood for the trees, for we are all looking for details and minutiae from individual sections, not paying enough attention to the broad facts of the architecture of this highly distinctive mountain mass as whole. Where the whole range is a jumble of block-faults and thrusts, many of them evident and a few of them obscure, we cannot derive much help from details of individual sections. In my opinion, therefore, the controversy should be given a holiday to brew over the many conflicting facts and details, which the admittedly hard and painstaking field work of the various contributors has unravelled. Enough materials and data now exist and if the subject is revived after ten years of further routine mapping with the purely objective outlook of field geology, an acceptable solution is bound to emerge from the present apparent chaos of opinions.

The present writer is committed to the view of the Tertiary age of the salt on the ground of the structural deformation the Salt Range has undergone, as a whole, and the consequent displacements of its inner anatomy through faults and thrusts. Since 1923, when he visited the Kohat area and in 1928-30, when he worked in the eastern Salt Range (Jogi Tilla area) and mapped parts of the latter in detail on 4"=1 mile scale, the conviction was forced on him that the geological interpretation of this unique terrain of simple and straightforward

*Mr. Wadia was not present at Udaipur and had not seen the papers, by Sahni, Sitholey, Lakhnapal and Trivedi, which were received late.—[Ed.]

stratigraphy lies in its overthrust structure and the consequent tectonic displacements its rock masses have undergone in reaching its present stage of mountain evolution. This work disclosed many sections in agreement with the views of Pascoe (1920), Vleck Anderson (1927) and Cotter (1933), with small modifications and adaptations in the more western parts of the Salt Range; and the recent discovery of minute fossil remains in the disputed series of beds has thus caused no surprise to the upholders of these views, who regard it as a welcome independent proof of the postulated structure. Professor Sahni's contribution to the interesting subject, when the controversy regarding the age and stratigraphy of the salt beds has ended, promises to be even of greater value in furnishing clues to the tectonic dislocations of the various parts of the Range and will also solve whether or not a bodily slide southwards of the bulk of the Range has occurred. It is hard to disbelieve or discount the evidence of fossils as presented by Sahni and his collaborators in their later papers. Those who do so take upon themselves the burden of proof how the micro-organisms occurring in well-bedded and laminated indurated oil shales, dolomite or salt, could have been adventitiously introduced in the body of the rock. Incompetence of strata, their plastic flow, crumpling and solution channels do not give satisfactory explanation of the presence of micro-organisms in the beds of rocks penetrated by borings of over 100 feet.

As stated above, the best chance of an early solution of the controversy is energetic extension of Mr. Gee's careful mapping to all parts of the Salt Range. What is needed is the study of the tectonics of the Range as a single unit, without paying too much attention to complexities of individual isolated exposure; or to their theoretical interpretation.

The most dominant fact in the geology of the Salt Range is its overthrust structure. The orogeny of the Potwar Plateau, of which the Salt Range is the southern escarpment face, is unique among the mountain structures of India. The uplift of the Range is not along a single individual orogenic axis, but is related to the epirogenic uplift of the Potwar geo-synclinal basin. There is no folding of the true mountain type involved, but only a block uplift and inversion at the south edge of the upheaved block. There is not much support for a long bodily slide of the Salt Range of the type of an Alpine nappe from its roots near the Kalachitta in the north. But there is an undoubted southerly thrust of the Palaeozoic over the down-thrown and severed southern limb, consisting of the far younger Eocene-Pliocene rocks in the eastern part of the Range. This thrust is observable at several points between the Jhelum and

Kalabagh; and the displacements seen here are of such intensity that the bottom Cambrian strata are, at some places, seen to over-ride late Miocene or Pliocene (Middle Siwalik beds of the summit). West of Khewra, for a considerable length of the Range, the thrust is obscured, being hidden under the alluvial deposits at the foot. Between the foot and the summit of the vivid line of escarpments, there are two, three, or, at places four thrust-planes, cleanly inserting wedges of the Eocene in the Palaeozoics, without any discordant junction or appearance of disturbance. This fact, coupled with the widely varying facies of the Ranikot-Laki-Kirthar Eocene sequence, as observed in different areas of the Punjab, Kohat, Khasor hills and Mandi—a thick group of marine limestones in one area; a rapidly varying succession of shallow water, coastal variegated clays and sands (gypseous, bituminous and sulphurous) in another and thick beds of alternating gypsum and salt in a third—may explain why the Salt Range Eocene salt is so sporadic in its occurrence and so puzzling and illusive in its outcrop and relations at all the localities where it occurs, e.g., Khewra, Mandi and Kohat.

In the present controversy, the role of thrusts in disturbing stratigraphic positions is not sufficiently recognised; even when recognised, its significance is not fully credited because of apparent lack of discordance in the bedding planes. While block-faults and numerous thrusts are acknowledged in individual sections at Chittidil, Daudkhel, Kallar Kahar, Warcha and Khewra, the part played by these thrusts in bringing about the apparent infra-Cambrian position of the salt-gypsum assemblage at its foot is disputed. In many of the sections under dispute, the mechanical contact is obscure and an apparently normal depositional sequence is simulated. Such deceptive contacts are not infrequent at some of the great *nappes* in the Alps where formations, widely divergent in age and facies, come in contact as if in normal superposition. The presence of mylonite and disturbed surfaces of junction, which are visible at some of these thrust contacts, disappear totally at other places some distance apart, where the same formations come in contact along the same plane of juxtaposition.

The thrust structure of the Salt Range, which is a matter of common observation and not of any hypothesis, is sometimes confused with the *nappe* hypothesis postulated by Cotter (1933) and by Gee (1934), which suggests bodily shift of the entire mountain mass of the Salt Range from the north, along its present sole. This view may be correct or not; but the mechanism which brought the Khewra-Warcha salt-gypsum beds under the Purple Sandstone

or the Talchir conglomerate, can be more simply explained by the dislocation and relatively small overthrust of the lower limb of an inverted anticline or monocline formed during the block upheaval of the Potwar plateau at a period so late as the Pliocene (post-Middle Siwalik).

Mr. Gee (1945) complains that there are many among the supporters of the Eocene view who have never studied the Salt Range on the spot. There is undoubted logic in this, but so many facts and data based on competent field work are now presented to the onlooker that he sees much of the game and is in a position to offer useful comments.

Dr. Lehner (1945) remarks that my profile section of the Potwar geosyncline (*Geology of India*, page 257, 1939) shows below the Salt Range scarp an inverted section that has no roots *in situ*. The accompanying diagram explains my meaning.

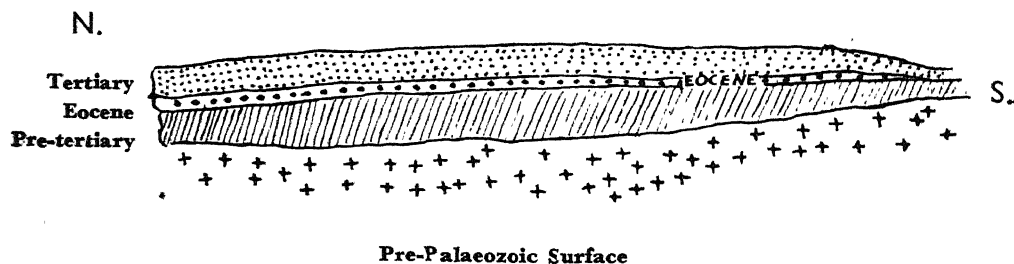


Fig. 1.—N. W. Punjab at end of Miocene period.

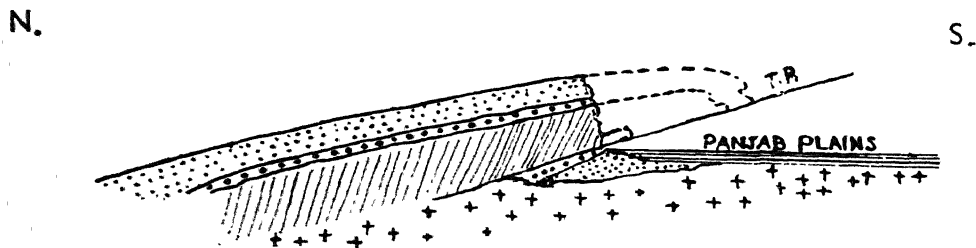


Fig. 2.—The scarp of the Salt Range Mountain after its formation at the end of the Tertiary.

COMMENTS ON THE SALT RANGE SYMPOSIUM.

By

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(Received 24 February 1946)

Professor Sahni has invited me to comment on the Salt Range symposium although I have no local knowledge. Faced with the conflicting evidence presented there, it seems to me clear that something is wrong and that the whole truth is not apparent. The case for the Tertiary age of the salty beds in the Salt Range seems won until pages 303 and 304 when the only verdict possible is non proven, and a strong presumption that the salty beds are Cambrian remains.

Dr. Lehner gives an excellent account of the Persian Salt formations and its scope may perhaps be wide enough to appease Sir Edwin Pascoe (p. 213). Lehner points out that a Cambrian and a Miocene salty series are known in Persia and that the former cannot be younger than Cambrian without invoking the presence of a thrust sheet 600 miles long and 350 miles wide for which there is no evidence. I have also seen salty beds of Lower Tertiary age in Laristan further north in Persia than the salt-plug region. Conditions when salt was deposited with red shales have recurred in Persia though Pascoe finds it hard to believe they can have done so in India (p. 208). Lehner compares the Persian and Punjab Cambrian sequences and finds that they are so much alike lithologically that conditions of deposition must have been "almost identical". He concludes that "the Punjab salt may also rightly belong to where it appears to be", although the aspect of the salty beds in the two districts is different. All this prepares one with Persian experience to find that the early beds of the Cambrian in the Persian basin of Tethys and the north west Indian basin may be much alike.

The location of the Salt Range in front of the ranges converging at the syntaxis of the north west Himalayas leads one to expect a zone of Jura folding and the unsticking this usually implies. The salty beds emerging round the margin of the Soan syncline seem to be an obvious lubricant. Gee's sections illustrate this conception which Lehner sketches diagrammatically (p. 264). Wadia's sections (pp. 216 and 218) give the impression of imbrication provoked

by obstruction when the Soan syncline grounded southwards as it was brought to rest. All this seemed to me clear and to be expected if the salty beds in the Salt Range be Cambrian. On the other hand one world-famous case of thrust mountains occurs in north west Scotland where the carriage forward has taken place on a sheet of lubricant younger than the beds which have travelled, and this a series of sediments easily weathered away when compared to their robust neighbours. It must have been a peculiar circumstance that left the sheet of "fucoid beds" exposed for the gneiss of that region to travel over. I recall this classical region because it would help if the edge of the Soan syncline had reached a sheet of Tertiary salty beds in its travels south, not that I think it did, but that by a long chance it might have done so.

The 1944 conference focuses light on Sahni's fossils and Gee's map and the attempts to emplace the fossils by windy stealth in salt "marl", oil-shale and dolomite are not very convincing. It is noteworthy that all Sahni's fossils are light and could be blown about and also that they are so fresh. L. J. Wills and others have found scorpions in Keuper marls which could also be easily transported and look very fresh without the find having disturbed the geological fraternity. Unfortunately Sahni's find is disturbing but it seems to have come to stay.

The examination of Gee's beautiful maps is convincing that a salty group underlies a sedimentary packet of Palaeozoic rocks as if unconformably and that the salty beds crop out 10 miles behind the main scarp. What is not clear is how far the Soan syncline has moved south. Is it only a few miles to have given rise to the imbricated tectonic ornament along its southern margin or has it come forward 50 miles or so as the embayment near Mianwali suggests? That there are many sections in which the Palaeozoic packet of the Soan syncline is parted from the Saline Series below by a thrust is clear, especially in some where the Talchirs overlap the Cambrian members of the complex. But then several of Gee's sections described on the pages from 297 onwards do not carry much conviction that they are really undisturbed, and in fact may be interpreted as indicating fault zones. The Tredian Hills and Ratta sections are however utterly confounding to the comfortable hypothesis of a tectonic break over all this Salt Range area between Saline Series and Palaeozoic mantle. These upset the apple cart and I have to admit that something is wrong but I do not know what. Any tale of the Salt Range which will explain the anomalies is still to be told.

THE AGE OF THE PUNJAB SALINE SERIES: A REVIEW.

Supplementary Note.

By

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(Received 18 December 1946)

The old controversy regarding the age of the Punjab Saline Series has been revived by the recent discovery of certain microfossils by Professor Birbal Sahni in some of these beds which seem to clearly indicate that the Saline Series is definitely *Eocene* in age, and *not Cambrian*. On reading through the first contributions—dealing with these newly discovered fossils, I was one of those who seriously doubted the reliability of this palaeontological evidence and was inclined to still support the view in favour of the—Cambrian age, which was based on geological and structural considerations. In the course of a Review Note which I sent to Professor Sahni about a year ago (a cyclostyled copy of which was circulated among the contributors to the Udaipur Symposium) I elaborated this point of view and argued that the microfossils which have been recovered from the saline beds may after all not be true *in situ* fossils. I pointed out that they may be *in situ* only in so far that they are in the place where they were first embedded, and not *in situ* in the sense that they were included in the rock at the time of its formation, and therefore of very doubtful validity as age indicators; and seeing that we are here dealing with saline beds characterised by their special and unique properties of softness, solubility, and plasticity, this suspicion that the micro-organic remains now found in them may be purely of an 'adventitious' origin was very strong, and it therefore appeared that we could not straightaway accept these fossils as reliable and convincing indicators of the age of the containing beds.

Since writing my first review in December, 1945, I have been able through the kindness of Prof. Sahni, to read through the several further contributions to the Symposium, including Mr. Gee's latest review (December, 1945) of the entire Discussion. On a fuller and more comprehensive reconsideration of the entire evidence, I must confess that the whole outlook in my first review is vitiated by the fact that undue emphasis has been placed only on the salt beds and their contained microfossils; and due regard has not been paid

except for a passing reference, to the fact, which has come out very pointedly in recent studies, that similar fossils are also found in the associated dolomites and oil shales. The possibility of looking upon these organic remains as adventitious in character, due to their intermittent infiltration into beds characterised by softness, solubility and plasticity, can hold good only in the case of the salt beds. It is difficult to extend this explanation to the fossils in the dolomites and it is almost impossible to accept it in regard to the fossils in the oil shales. Oil shales of different ages have been studied in several parts of the world, and have everywhere been considered as sedimentary in origin and it has always been assumed,—and there is no reason to think otherwise—that the organic remains which they contain in each case belong to the contemporary faunas and floras. It is now clear from Prof. Sahni's studies that quite a large number of organic remains are found in the oil shales and in some cases, the proportion of such organic matter is more than 50% of the rock. These fossils in the shales must be admitted as truly *in situ*, having been enclosed in the rock at the time of its formation and, as such, must be looked upon as undoubted indicators of the age of the containing beds. Thus even if, for a moment, we ignore all the fossils from the salt beds and dolomites whose reliability it may be possible to question, we are still left with the oil shales, and the evidence of the fossils in these is surely against their being Cambrian in age.

To enable us to extend this conclusion regarding age to the entire Saline Series, all that we have to make sure is that these oil shales are really part and parcel of this Series. On this point, there is evidently no doubt. All the field geologists, including Mr. Gee, agree in thinking that the oil shales are definitely an integral part of the stratigraphical succession included in the Saline Series; if so, the palaeontological evidence from the oil shales put forward by Prof. Sahni is convincing and decisive. The Saline Series cannot be Cambrian in age; they are very much younger and this conclusion must be considered as being reinforced by the occurrence of a *similar* series of organic remains in the dolomites and salt beds, all the fossils forming together a consistent assemblage offering no "palaeontological puzzle" such as one would expect on the basis of the 'infiltration' theory.

Now to the tectonic aspect of the problem. In the case of an unfossiliferous bed in a highly disturbed area, whose age it is not possible to determine on the direct internal evidence of fossils, the study of the structure and tectonics

of the area in which the bed and its associated rocks are found will no doubt be helpful in determining the age of the bed in question. This was the method of attack adopted by Indian geologists in tackling the problem of the age of the Saline Series, since they all started with the idea that they were here dealing with an unfossiliferous series of beds; and on the question of the interpretation of the tectonics of this part of the Salt Range, we know how sharply and variously opinion has been divided. The present discovery of undoubted *in situ* and recognisable fossils in one of the members of the series, *viz.*, the oil shales, affords clear internal evidence of the age of these beds; and this fact alters the whole complexion of the tectonic aspect. For, when once we begin to deal with the field relationships of fossiliferous beds whose ages can be determined on the internal palaeontological evidence, the verdict of the fossils becomes supreme, and we are no longer at the mercy of tectonic interpretations for the age determinations of the concerned beds. On the other hand, the known ages of the beds must help us in deciding the acceptability, or otherwise, of any field interpretation.

This is now the position regarding the Saline Series of the Salt Range. They can no longer be considered unfossiliferous; truly *in situ* and recognisable fossils have been noticed in the oil shales; and the oil shales are admittedly part of the Saline Series. Therefore these fossils in the oil shales determine, at least in a general way, the age of the Saline Series as a whole. The verdict of these fossils is definitely *against* the Cambrian view. This basic fact must now direct and control the tectonic interpretation of the area.

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A STUDY OF THE KARYOTYPES AND THE OCCURRENCE OF DIPLOID MALE GAMETOPHYTES IN SOME SPECIES OF THE GENUS *EPHEDRA*

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(*With five plates and twenty nine text-figures*).

(Communicated by Dr. B. Sahni, F. R. S.)

(Received 8th January, 1944)

ABSTRACT

A new technique in making chromosome studies has been evolved in the genus *Ephedra* which consists in making smears of the germinating pollen grains. This has yielded uniformly excellent results. This method of handling very minute objects can equally be applicable in the case of other microscopic organisms without much loss of material.

Chromosome numbers have been counted and their morphology studied in 7 species, 6 Asiatic and one North African. The haploid chromosome number in *E. foliata* Var. *Ciliata* and *E. gerardiana* is 7 while in *E. intermedia* Var. *tibetica*, *E. saxatilis*, *E. sinica*, *E. likiangensis* and the North African *E. altissima* Var. *Algerica* is 14.

The separation of variety *saxatilis* of *E. gerardiana* as a distinct species recently done by Fløin on taxonomic basis is upheld in the light of the cytologic study of the chromosomes of the two.

The basic chromosome number for the genus is 7. Polyploidy, though not of a high valence, has been frequent in the evolution of the species in the genus. Aneuploidy does not seem to have played any part.

There seems to be a fairly stable 'Basic Karyotype' for the genus (at least the section *Pseudobaccatae*) which includes 2 chromosomes with sub-terminal kinetochore and 5 with median or sub-median kinetochore. All the tetraploids with 14 as the haploid chromosome number are marked by possessing 4 chromosomes of the first type and 10 chromosomes belonging to the second type thus including two-basic sets. There are, of course, differences of detailed nature in the individual chromosomes of the 'Basic Karyotype' in the different species.

It is remarkable that every species is found to possess either statellites or secondary constrictions or both in some members of the set. The invariable occurrence of these is highly significant in view of the recent researches tending to associate these with the formation of nucleoli in the nucleus.

There seems to be an innate tendency in many species of the genus to produce diploid pollen grains in small numbers besides the haploid ones. In 4 species, namely, *E. foliata*, *E. altissima*, *E. intermedia* and *E. saxatilis* out of 6 investigated from this point of view, they are observed. This phenomenon is not reported in any other *Gymnosperm*.

The diploid grains are as functional as the haploid ones and produce diploid male gametes. Somatic pairing is noticeable between the corresponding chromosomes of the doubled complement in the mitosis of the body nucleus of these diploid grains during their germination.

Seven different species of the genus *Ephedra* have been studied in the present investigation, namely, *E. foliata* Boiss var. *ciliata* Stapf, *E. altissima* Desf var. *Algerica* Stapf., *E. intermedia* Shrenk et Mey var. *tibetica* Stapf, *E. gerardiana* Wall, *E. saxatilis* Royle, *E. sinica* Stapf, *E. likiagensis* Florin. All the species are Asiatic excepting *E. altissima* which is met with in the North West Africa.

Of these *E. foliata* var. *ciliata* grows in a wild state in some parts of the Punjab plain. The plants of all the other species excepting *E. gerardiana* have been raised from seeds in the Government College Botanic Garden, Lahore. The seeds of *E. saxatilis* were kindly collected by late Prof. Kashyap from Zanskar (12,000 ft.) in August 1928 and sown in October the same year, those of *E. intermedia* were supplied by Mr. I.P. Mohan I.F.S. of the Forest department, Punjab (Lahore circle) collected from Chini range (Bashahr division) in 1937 and sown the same year while those of *E. sinica*, *E. likiagensis*, *E. altissima* were received from the United States Department of Agriculture, Washington, in the year 1938 through the courtesy of Mr. B. Y. Morrison—Principal Horticulturist in charge. To all these persons the writer's grateful thanks are due. All these cultivated plants have remarkably adapted themselves to the climate of the Punjab. They are thriving very well, bear flowers and set seeds.

All these species belong to the section *Pseudo baccatae* Stapf—which is decidedly the largest section of the genus. Two of these, namely, *E. foliata* and *E. altissima* belong to the Tribe Scandentes Stapf, one, namely, *E. intermedia* to the Tribe Pachycladae Stapf while the remaining four to the Tribe Leptocladae Stapf. No representatives of the last fourth Tribe of this section, namely, *Antisyphiliticae* Stapf is investigated.

In the case of *E. gerardiana* the chromosome studies have been made exclusively from the sections of the female gametophytes. The ovule of this species were fixed in Bouin's fixative from plants growing in their natural state at Kiangchhu plain in the Western Tibet at an altitude of about 15,000. ft. in August 1932 when the writer accompanied the late Professor Kashyap to these parts. In all other cases the cytological investigations have been made chiefly from the smears of the germinating pollen grains prepared by a new method devised by the author which has given uniformly excellent results. The details of the process are as follows:

Germinating pollen smear technique—

The pollen grains in all the species of the genus *Ephedra* possess at maturity a sculptured exine with ridges and grooves running longitudinally from pole to pole. The mature pollen grain at the time it is shed consists of remains of the evanescent vegetative cells on one end, a stalk nucleus embedded in the peripheral part of the cytoplasm of a naked body cell in the centre and a rather large tube nucleus at the other end.

The pollen grains are germinated on the mucilage secretion that oozes out of the ripe ovules from their micropylar ends. This drop is received on glass slides and ripe pollen grains are shed on it. The slides are then placed in a moist chamber. Pollen grains of any species of the genus can grow on the mucilage secretion of any other species with equal vigour as on its own. The grains gradually absorb the nutritive medium, swell in size and at the same time prophase changes start in the body nucleus. On the pollen grains becoming highly turgid, the exine ruptures by two splits starting on the opposite sides of the tube nucleus end of the grain and extend to about the middle of its length. This throws out the grain bounded by the intine with a jerk from the inside of the outer spore coat which immediately undergoes torsion. Thus liberated, the grain increases to about $1\frac{1}{2}$ to double its former size. This has been called '*spindle gametophyte*' in the body of the paper to differentiate it from an ordinary pollen grain with exine intact. By this time the body nucleus is in the mid-prophase or early metaphase stage (early prophase changes having occurred when the exine was still intact). All the further changes occur outside the exine within the medium.

The grains at any desired stage of the mitotic division of the body nucleus are fixed by putting two or three drops of a suitable fixative on the slide. The fixative is allowed to act for two to four hours but a prolonged action of the fixative upto 12 hours does no harm. The precaution taken is that the fixative on the slide is not allowed to evaporate and the slide is, therefore, kept in a moist chamber. The most delicate part now is the handling of these microscopic objects.

A clean slide is smeared with Meyer's albumen and the drop of the fixative with the grains suspended in it is poured on it. This is now spread uniformly over the slide by gently tilting the slide in various directions. If the fluid is not enough a drop or two of water may be added. This is done to ensure the uniform distribution of the grains over the slide. A long coverslip is next placed on the slide just as in making balsam mounts. The

liquid is then carefully sucked out by gently placing a piece of blotting paper on one side of the coverslip. Some of the grains may be sucked out in the current but mostly they remain in position. This suction is carried to such an extent that any further withdrawal of water introduces air bubbles under the coverslip. The pressure exerted on the grains by the weight of the coverslip reinforced by the adhesive force of the disappearing film of water on the coverslip is sufficient to fix the tiny objects to the albumen coating on the glass slide. The coverslip is now removed by flooding the slide with water and gradually and carefully sliding away the coverslip under water when the force of buoyancy facilitates the process a great deal. Some of the grains are sure to be washed away during the process but a vast majority of these stick to the slide.

The next process is washing. If the fixation is done in the chrom-acetic mixtures the slides are washed in ordinary stender dishes in flowing water at least overnight. If Bouin's fixative is used the process takes longer time but gives excellent results. The slides in the latter case are first washed in water for about 2 minutes to remove the superficial fixative and then passed through the various grades of alcohol to remove all traces of picric acid. In 30%, 40%, 50%, they are kept at least overnight in each. They are then passed back in the reverse order through the successive lower grades keeping in each for about four hours till they are brought back into water. The washing is further completed in running water for about 4-6 hours. This process must be strictly followed to ensure the complete removal of the fixative before proper brilliancy of stain in the preparation can be obtained.

The slides are now ready for staining in the usual way. Two to three hours mordanting in iron-alum and 2-3 hours staining in $\frac{1}{2}\%$ Haematoxylin give excellent results. The chromosomes take a jet black colour against the greyish white background of the cytoplasm.

An important point in mounting the preparations in balsam is that the balsam should be thin, otherwise the grains are liable to undergo plasmolysis.

The technique above described for handling microscopic objects can as well be utilised with great advantage for making cytological investigations of such minute objects as *Desmids*, *Pleurococcus*, fungal mycelia, etc., which are otherwise difficult to handle.

Bouin's fixative with Allen's modification P.F.B¹⁵ has been almost exclusively used in the present investigation with excellent results.

A further modification adopted in the present case has been the employment of colchicine in doses of 0.2-0.4% and sulfanilamide in 0.5% dose to the medium for germination of pollen grains which resulted in the scattering of chromosomes through the loss of spindle mechanism. This has given exceedingly beautiful preparations for the study of exact chromosome morphology. This modification is employed as a supplement to the investigation made from preparations showing the normal division of the body nucleus in the natural mucilage secretion. In these species, while the chromosome studies are mainly done on smears of germinating pollen grains, in some of them observations and countings have also been done at other stages in the life cycle.

OBSERVATIONS.

E. foliata Boiss var. *ciliata* (C. Mey) Stapf.

In this species pollen grains possess 14—15 ridges alternating with a similar number of grooves on the exine.

In a previous preliminary communication the writer¹¹ stated the haploid chromosome number for the species to be 7 determined from the division of the body nucleus of the pollen grains germinated on natural mucilage secretion. Later Maheshwari¹⁰, while not mentioning the definite chromosome number for the species, reported the haploid number to be "certainly not more than 7" seen during the division of the central cell nucleus in a developing archegonium. Mulay¹³ afterwards stated from the observations made on certain plants of the species growing in the neighbourhood of Karachi that the chromosome number is definitely more than 7.

It can be stated that the haploid chromosome number for this species is 7 beyond doubt. This is unmistakably observed in the normally germinating pollen grain with the chromosomes of the body nucleus at the metaphase seen in Photo 1 Pl. I and in the pollens which were germinated on mucilage secretion containing 0.5% sulfanilamide. In these latter the 7 scattered chromosomes are clearly observed in the absence of a spindle during the mitosis of the body nucleus (Photo 2, Pl. 1).

Chromosome counts have also been made in this species during the first meiotic division in a study of the microsporogenesis. Figure 2 shows 7 bivalents forming chiasmata at diakinesis.

A further verification was also made from the sections of the root tips. The root tips from freshly germinating seeds were submerged in 0.4% colchicine solution in water for two hours prior to fixation which was done in Bouin's fixative. Figure 1 shows a periblem cell from this root tip in which the

elongated chromosomes lie scattered because of absence of spindle formation. Fourteen chromosomes are clearly counted representing the diploid chromosome complement.

Thus the haploid chromosome number for the species is 7 and the diploid 14 beyond doubt.

It is of interest to note that the chromosomes at the first meiotic division are shorter and thicker than the chromosomes formed during the normal mitotic division of the body nucleus as seen in a comparison of Figs. 2 and 3, 4.

The karyotype—

The morphology of the chromosomes is exclusively studied from the smear preparations of the germinating pollen grains and is illustrated in Figs. 3, 4 showing the chromosomes of the body nucleus at metaphase plate. The first of these figures is drawn from the grain shown in Photo 1 Pl. 1.

Two chromosomes 'a', 'b' possess median kinetochore. Of these 'a' is distinguished from chromosome 'b' by its larger size and also by the fact that it possesses a secondary sub-terminal constriction in one of the arms (Fig. 3, Photo 1 Pl. I). The secondary constriction may or may not be clearly observed in the different stages of the nuclear division but is usually more marked at the anaphase when the chromosomes undergo stretching.

Chromosome 'c' possesses very slightly sub-median kinetochore—a fact which can be appreciated only in very clear preparations and under high magnification.

Two chromosomes 'd' and 'e' possess distinctly sub-median kinetochore with one arm conspicuously longer than the other. Chromosome 'd' is distinguished from 'e' by its larger size. Again the longer arm in 'd' is

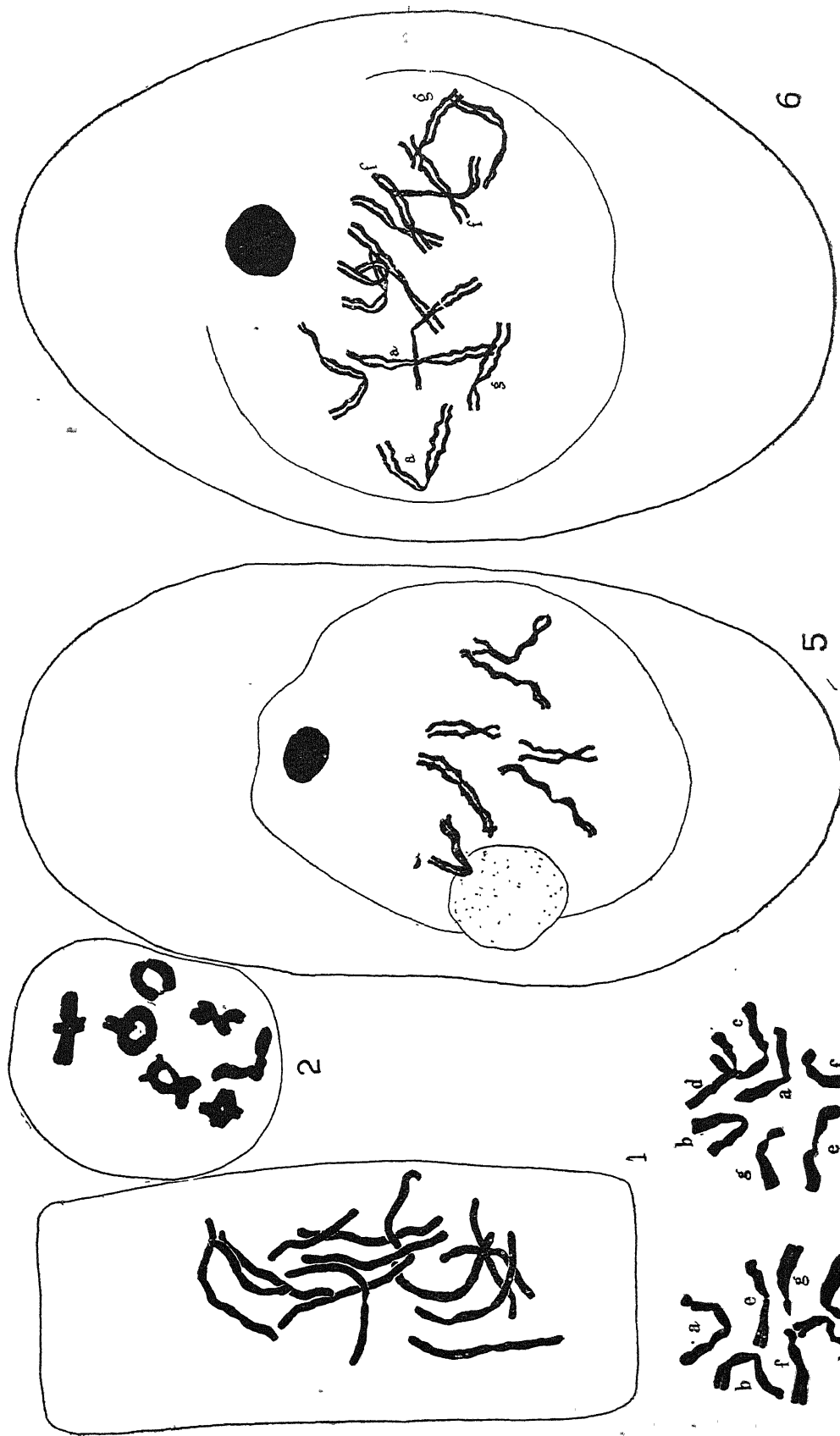
EXPLANATION OF TEXT FIGURES

(All figures drawn with camera lucida, x 2760. The dark coloured sphere within the 'spindle gametophyte' is stalk nucleus while the large dotted one is tube nucleus).

E. foliata (1-6)

1. Diploid chromosome complement in a perilem cell of root tip treated with 0.4% colchicine for 2 hrs. 28 chromosomes are scattered in the absence of spindle mechanism.
2. Microspore mother cell showing 7 bivalents at diakinesis.
3. & 4. Chromosomes at metaphase of normally dividing body nucleus of haploid grain grown in natural secretion.
5. Haploid 'spindle gametophyte' grown in 0.2% colchicine containing secretion. Slightly pressed in the smear preparation.
6. Diploid spindle gametophyte grown in 0.2% colchicine containing secretion. Slightly pressed in smear. Tube nucleus not shown.

Mehra: Karyotypes and diploid male gametophytes in *Ephedra*



about $1\frac{1}{2}$ times the length of the shorter arm while in 'e' the longer arm is about $1\frac{1}{2}$ times the shorter arm.

Two chromosomes 'f' and 'g' belong to the category of chromosomes with sub-terminal kinetochore and can be spotted out with the greatest ease in the complement (Photo 2, Pl. I). The proximal end of these chromosomes is like a knob which sometimes appears blunt, at other times pointed while the distal arm is elongated. Chromosome 'f' is distinguished from 'g' by its larger size. Also perhaps the chromosome 'f' possesses a secondary sub-terminal constriction in the longer arm. This was observed in one figure at anaphase when the daughter chromosomes were stretched but has not been confirmed.

One very striking feature is that even an intensive study of a very large number of nuclear figures at different stages of mitotic division failed to show any chromosome possessing a trabant or a satellite in the species while in all the other species studied from preparations of a similar nature of germinating grains some in the complement invariably possess satellites.

Secondly all the pollen grains resemble one another in possessing apparently exactly similar sets as far as the morphology and size of the corresponding chromosomes is concerned. In other words the male plant does not appear to be visible heterogametic.*

Diploid pollen grains—

One of the most striking things in the present species as also in some other species of the genus *Ephedra* investigated in the present paper is the production of diploid grains besides the normal haploid ones. They are observed in *E. foliata* but rather more frequently in *E. altissima* *E. intermedia* and *E. sexatilis*. With respect to these last species this feature is discussed later.

So far as *E. foliata* is concerned the diploid grains are observed in plants growing in nature in their own home under perfectly normal conditions of life and consequently this feature cannot be alluded to any external cause but to an innate tendency of the species.

The diploid grains are larger in size than the haploid ones, almost double their volume and consequently the '*spindle gametophytes*' liberated out of them

*It may be pointed out that observations on a large number of plants growing in nature in Chhanga Manga Forest and Pabbi hills have invariably shown that male and female plants in *E. foliata* var *ciliata* are distinct. Stapf¹⁹ in his general description of the species, however, states that the plants may be monoecious or dioecious although he says nothing regarding the individual varieties. It can be stated that so far as the writer's observations on plants growing in nature are concerned at least the var. *ciliata* seems to be strictly dioecious. Mulay¹³ has come to the same conclusion from his observations of plants of this variety growing in a wild state near Karachi.

when the exine is cast off show the same proportionate difference in size (Photo 3 Pl. I). During the pollen grain germination studies when diploid grains were noticed here and there scattered amongst the haploid ones on the slide, a dose of colchicine in some cases and sulfanilamide in others was purposely administered to scatter the chromosomes with a view to facilitate accurate counting of the chromosomes. One such diploid grain and another haploid one, both from the same slide treated with colchicine and somewhat pressed during the preparation of the smear are shown in Figs. 6 and 5 respectively. Fig. 6 is drawn from the grain shown in Photo 4 Pl. I. Clearly the entire haploid set has been duplicated in the diploid grain and each chromosome is represented twice over. Four chromosomes with sub-terminal kinetochore 'ff' and 'gg' are observed in the diploid grain in contrast to only two 'f', 'g' in the haploid one. Similarly each of the other chromosomes of the set from 'a—e' is represented twice over in the diploid grain.

From the position of the corresponding chromosomes in the colchicine treated diploid grain, indications of somatic pairing before the loss of spindle is noticeable. The members of some of these pairs are still observed to be more or less parallelly disposed.

The size of the stalk and the tube nuclei in the diploid grains is almost double their respective size in the haploid ones (Figs. 3, 4, Photo 3).

Ephedra altissima Desf. var. *Algerica* Stapf.

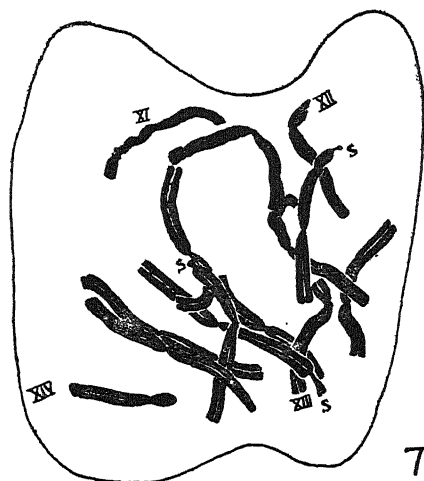
The number of ridges and grooves on the exine of the pollen grain vary from 13-17 with 14 or 15 as the most frequent number.

Berridge¹ reported the chromosome number in the species to be about 12. This she observed during the division of the central cell of the archegonium to form the ventral canal nucleus and the egg. Resende (in Tischler²² has) doubtfully mentioned the haploid number for the species to be 14.

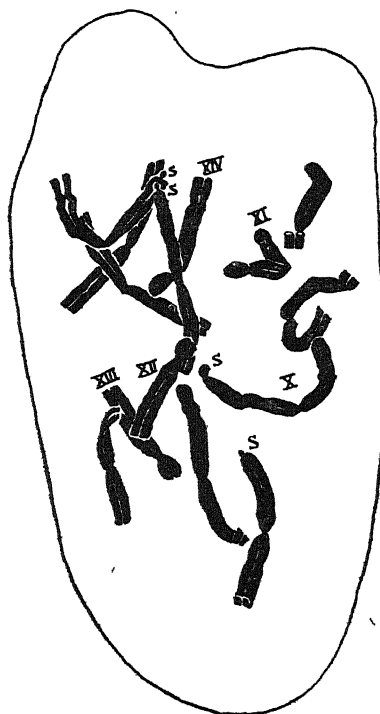
Present investigations based on the observations of a large number of exceedingly clear smears of germinating pollen grains, both treated with colchicine and untreated normal ones, show conclusively the chromosome

E. altissima (7-10)

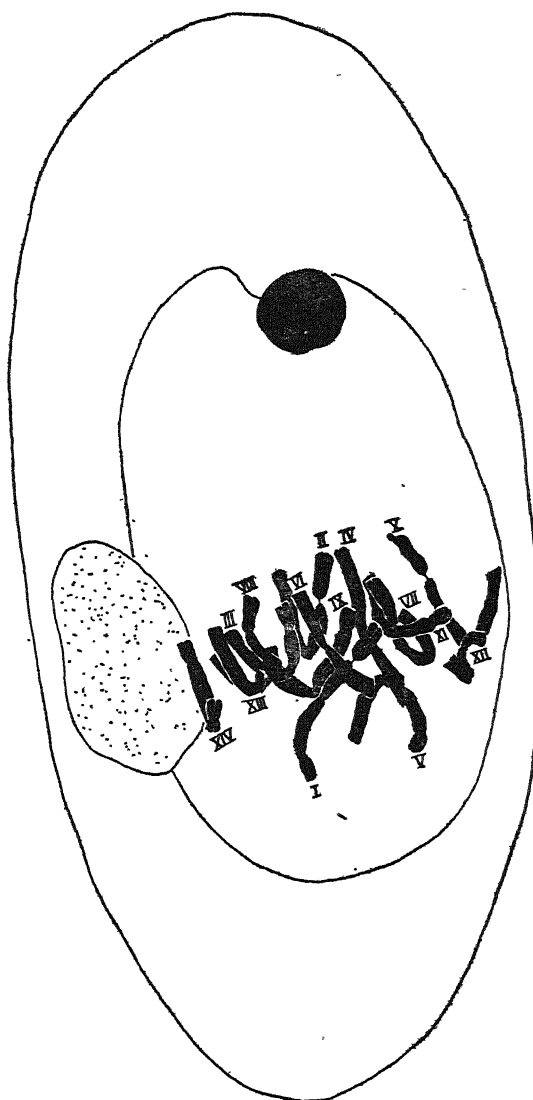
7. 8. Scattered chromosome complement within the body cell in 0.2% colchicine treated grains.
9. Haploid '*spindle gametophyte*' with chromosomes of body nucleus at metaphase in a grain grown in natural secretion.
10. Diploid '*spindle gametophyte*' germinating in 0.2% colchicine containing secretion. The daughter chromosomes of the original 28 chromosomes have separated. Tube nucleus not shown. Slightly pressed in the smear.



7



8



9



10

number to be 14. Two of such smears treated with colchicine are shown in Figs. 7, 8 (only the body cell shown) and an untreated one with chromosomes arranged at the equator of the spindle is shown in Fig. 9 also seen in Photo 5 Pl. I. All of these show 14 chromosomes beyond doubt.

The karyotype—

The chromosomes are quite long and many of them of approximately the same size. Out of 14, ten chromosomes marked I—X (Fig. 9 drawn from grain seen in Photo 5 Pl. I) possess median, slightly sub-median or distinctly sub-median fibre-attachment region. The position of the kinetochore is similar in some of these chromosomes, in others so slightly and gradually different that it is not possible to identify with certainty all the individuals of the set excepting the significantly different chromosome marked 'X' in the figure which is the largest of the complement. In this the position of the kinetochore is so distinctly sub-median that there is appreciable difference between the longer and the shorter arm. Besides it possesses a wide secondary constriction in the longer arm (Photo 5, Pl. I) and the piece so separated from the main body of the chromosome further possesses a satellite at the end. The satellite is not come within the focus in the photograph but is seen in Fig. 9.

In all, 3 chromosomes marked I, II, X, out of these ten chromosomes, possess definitely a secondary constriction each which is wide and highly conspicuous in one of the arms as seen in Fig. 9. Indications of the presence of secondary constrictions in some other chromosomes are also visible. Finally four out of these ten chromosomes marked 'S' in Figs. 7, 8 possess a satellite each at the end of one of the arms. As previously pointed out for *E. foliata* all of these secondary constrictions or satellites may not be clearly visible in every preparation depending upon the orientation of the chromosome and the type of fixation.

The other four chromosomes marked XI, XII, XIII, XIV possess sub-terminal kinetochore and belong to the 'f', 'g' category of *E. foliata* karyotype. One of these XIV probably possesses a secondary constriction at the end of the longer arm (Fig. 9).

Diploid grains—

Diploid grains are commonly observed in this plant. They are formed to the extent of 4-5% of the entire output of the pollen and are found indiscriminately distributed amongst the haploid grains in almost every smear preparation. The diploid grains which almost look like 'giant' grains in contrast to the haploid ones are about double the size of the latter. Mostly they

possess a symmetrical outline but here and there some of them show an outline indicative of two incompletely separated pollen grains. Such external forms of diploid grains have also been frequently observed in *E. saxatilis*.

The 'spindle gametophytes' liberated out of these grains after the exine is thrown off, are also about twice the size of the haploid 'spindle gametophytes'. Photo 6 Pl. II shows a haploid and a diploid gametophyte both at the metaphase in side view. Although the chromosomes in none of these can be counted but a rough idea is obtained that the number in the larger grain is double than in the other. In Photo 7 Pl. II is seen a diploid grain at anaphase. Photo 8 Pl. II shows again a haploid and a diploid gametophyte side by side both having already formed the male gametes. The size of the male gametes in the diploid gametophyte is double than those in the haploid one.

Also it is seen that the size of the stalk and the tube nuclei in the diploid grain is double their respective size in the haploid one.

One of the diploid gametophytes treated with colchicine is shown in Fig. 10 and the same seen in Photo 9 Pl. II. In this case the daughter chromosomes have separated and 56 such daughters can be counted. Evidently they are formed by the splitting of the original 28 chromosomes, proving thereby that the gametophyte is diploid. It will be observed that mostly the two daughters from the same parent chromosome still lie parallel to one another Figs. 10, 1 & 2, 3 & 4, 5 & 6 etc.

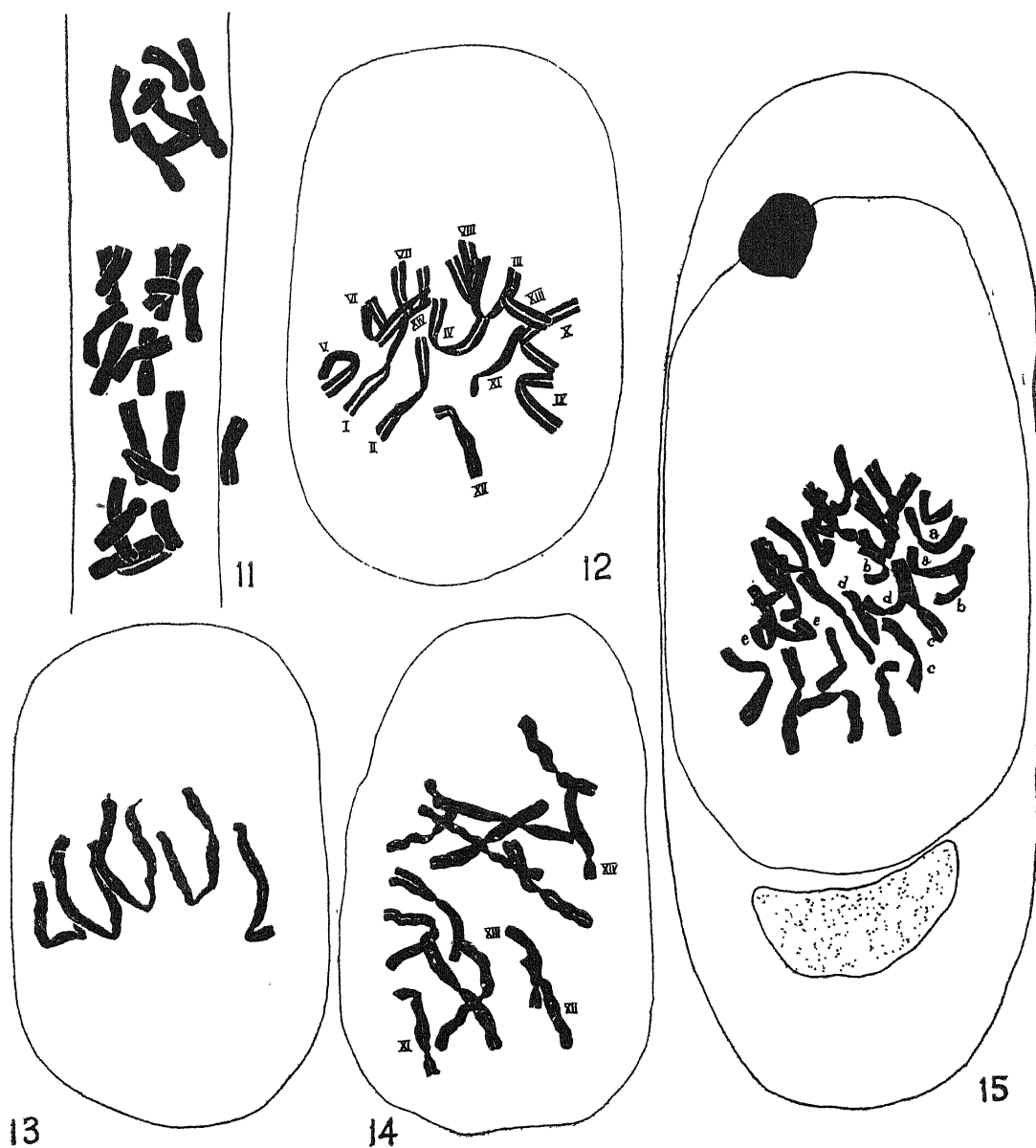
Ephedra intermedia Shrenk et Mey var. *tibetica* Stapf.

In the pollen grains of this species 9-11 ridges are present on the exine alternating with the same number of grooves.

Chromosome investigations have been made principally from the smears of the pollen grains germinating in normal secretion as well as those germinating in colchicine and sulfanilamide containing medium. The haploid chromosome

E. intermedia (11-15)

11. Diploid chromosome complement in a plerome cell of root tip treated with 0.2% colchicine for 26½ hours. 28 scattered chromosomes observed.
12. Chromosomes at metaphase plate in normal mitotic division of body nucleus from polar view within the body cell of a haploid grain.
13. Chromosomes at metaphase in normal division of body nucleus laterally viewed. Grown in natural secretion.
14. Scattered chromosome complement in body cell of a haploid grain grown in 0.2% colchicine containing secretion.
15. Diploid 'spindle gametophyte' 28 chromosomes spread at metaphase plate in a grain grown in natural secretion.



number for the species is 14 beyond doubt. This has been observed in a large number of smear preparations at metaphase and anaphase, in normally germinating grains. Fig. 12 shows one of these where 14 chromosomes are observed at metaphase plate. Fourteen chromosomes are similarly unmistakably observed scattered within the boundary of the body cell after the loss of the spindle in pollen grains treated with colchicine and sulfanilamide. One such treated with colchicine is shown in Fig. 14 and Photo 10 Pl. III. Another treated with sulfanilamide is seen in Photo 12 Pl. III.

The diploid chromosome number is studied from sections of root tips treated with 0.2% colchicine for 26 hours. The chromosome complement from a cell of the plerome region of the treated root tip is shown in Fig. 11. The chromosomes have become rather condensed due to the effect of the drug and lie scattered. They are 28 in number. One chromosome lies outside the cell boundary evidently pushed out by the stroke of the razor during sectioning.

The karyotype—

Chromosome morphology is studied from pollen grain smears exclusively. Ten chromosomes possess median, slightly sub-median or distinctly sub-median kinetochore. There are slight and gradual differences among them regarding their length and the position of the kinetochore and consequently individual members of this category cannot be distinguished with certainty. Amongst these one chromosome with sub-median kinetochore possesses a satellite at the end of each arm. This is seen in Fig. 13 showing the chromosomes at early metaphase in lateral view. Not all the chromosomes are drawn in this figure. In the same figure is also seen a chromosome with sub-median kinetochore bearing a secondary sub-terminal constriction in one arm.

Remaining four chromosomes marked XI, XII, XIII, XIV in Figs. 11, 15 possess sub-terminal kinetochore.

'Somatic pairing'—It is observed that pairs of more or less similar chromosomes are loosely placed together at metaphase in this species. Thus in Fig. 12 showing a metaphase plate pairs of chromosomes I & II, III & IV, V & VI and so on are seen to lie more or less near one another, in some cases with their arms parallel. This phenomenon is seen in a number of other metaphases as well. Even in the colchicine treated preparation shown in Fig. 14 where the spindle is lost, the chromosomes have not as yet much altered their original disposition and pairs of more or less regularly disposed chromosomes with the corresponding members lying parallel to one another are observed.

Perhaps in this species the two sets constituting the haploid complement are very much similar and the corresponding chromosomes tend to be associated together in the mitotic figure.

Diploid gametophytes—

Diploid gametophytes are not uncommon in this species. About a dozen are present in every 500 gametophytes examined which comes to approximately 2-3%.

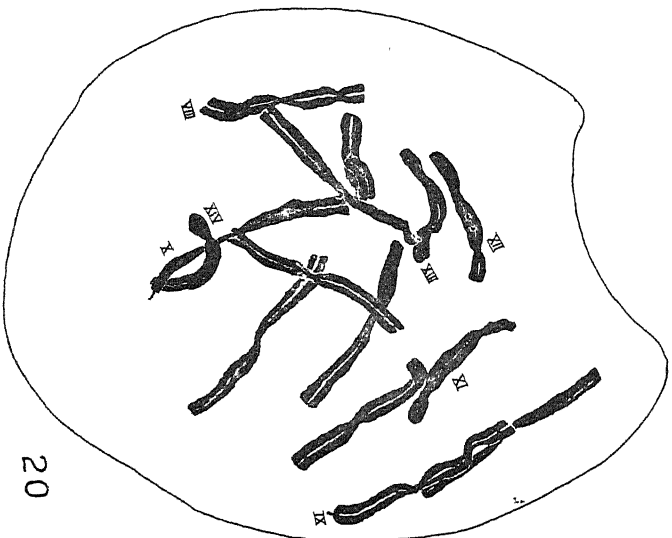
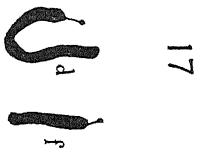
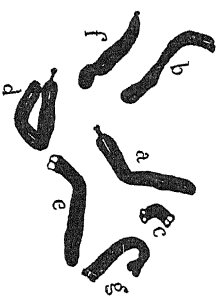
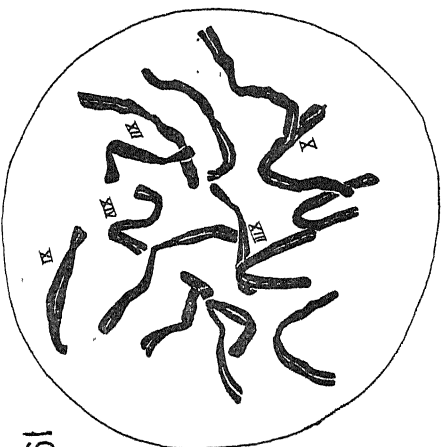
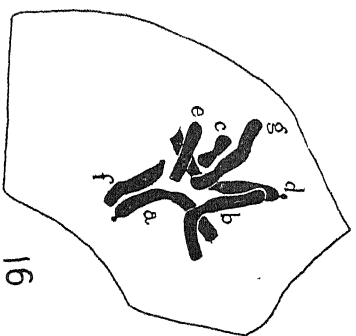
The size of the diploid '*spindle gametophyte*' is about double that of the haploid one. (Photos 11, 14 Pl. III). Also the body cell size of the former is about double that of the latter. The size of the stalk and the tube nuclei in the diploid gametophyte is also about double their respective size in the haploid one. Photo 11 shows a diploid and a haploid gametophyte side by side. The chromosomes are at metaphase in both and although not clearly counted roughly seem to be double in number in the larger compared to the smaller. The chromosome number 28 is clearly counted in another diploid gametophyte where the chromosomes are in the form of a plate at metaphase drawn in Fig. 15. Sulfanilamide preparations are even more instructive. Photo 14 Pl. III shows again a haploid and a diploid '*spindle gametophyte*' treated with sulfanilamide side by side and another diploid one similarly treated is shown in photo 13 Pl. III. The chromosomes in these are scattered and although all the 28 in the case of the diploid gametophytes have not come within the focus, these can be counted without the least difficulty in actual preparations.

Somatic pairing—In the diploid gametophyte showing the mitosis of the body nucleus with intact spindle seen in Fig. 15 the homologous chromosomes are arranged in pairs with their arms more or less parallel to one another *viz.* aa, bb, cc etc., on the equatorial plate.

Ephedra gerardiana Wall.

E. gerardiana has not been grown in Lahore and consequently no viable pollen was available for germination. The study of the chromosome complement in this species is based upon the dividing nuclei of the cells of the female gametophyte from the material of ovules fixed in Bouin's fixative at Kiangchhu plain in Tibet at an altitude of about 15,000 ft.

The haploid chromosome number is definitely 7 as seen in the two photographs 15, 16, Pl. IV.



The karyotype—

Five chromosomes 'a—e' seen in Figs. 16, 18 possess median or sub-median kinetochore. Of these probably three 'a', 'b', 'c' possess median kinetochore. Chromosome 'a' and 'b' are about the same size but the former is distinguished from the latter by possessing a satellite at the end of one arm. Chromosome 'c' is much smaller than either of the first two. It is as a matter of fact the smallest chromosome of the complement and is easily recognised in photos 15, 16, Pl. IV. Amongst the chromosomes 'd' and 'e' with sub-median constriction, 'd' is bigger than the other and possesses a satellite at the end of the shorter arm.

Of the rest two chromosomes 'f' definitely possesses a sub-terminal kinetochore and also a satellite at the end of the longer arm. This is particularly well marked in Fig. 18 where only two satellite chromosomes 'd' and 'f' are shown, the remaining chromosomes not having been drawn. The position of kinetochore of chromosome 'g' is not very clear but is probably also sub-terminal.

Thus in all 3 out of 7 chromosomes bear satellites.

E. saxatilis Royle.

This plant was formerly included under *E. gerardiana* as variety *saxatilis* by Stapf.¹⁹ Consequently the plants raised in the botanical garden, Lahore, from the seeds of this plant collected by late Prof. S. R. Kashyap from Zanskar were called *E. gerardiana*—the varietal distinction following Hooker⁸, Parker¹⁴, and Brandis³ having not been recognised. Therefore in a previous preliminary communication, the chromosome number of this plant was given under *E. gerardiana*. Florin⁷ in the systematic survey of Asiatic species of *Ephedra* considered it sufficiently distinct from typical *E. gerardiana* to rank as a distinct species. The chromosome complement of typical *E. gerardiana* Wall has now been worked out by the writer and in the light of the knowledge of chromosome complements of typical *E. gerardiana* and this plant the distinction between the two as distinct, though allied species, seems to be fully justified. The haploid

E. gerardiana (16-18)

16. Chromosomes in a cell of the female gametophyte.
17. Chromosome complement in a cell of female gametophyte. Chromosomes spread out in drawing. In original preparation they are compact.
18. Two Sat. chromosomes drawn from the set in a cell of the female gametophyte.

E. saxatilis (19-21)

19. Haploid 'spindle gametophyte' from polar view. Chromosomes at metaphase. Grain grown in natural mucilage.
20. Chromosomes scattered within body cell in a haploid grain grown in secretion with 0.5% sulfanilamide.
21. Diploid 'spindle gametophyte' (slightly pressed). 28 chromosomes at normal metaphase, grain grown in natural mucilage.

chromosome number in *E. gerardiana* as above described is 7 in contrast to 14 in *E. saxatilis*. The latter also does not represent the doubling of exactly similar chromosome set met with in *E. gerardiana*, there being differences of detailed nature in the chromosomes so far as satellites and sub-terminal constrictions etc. are concerned.

In *E. saxatilis* ridges on the pollen grain exine are 11-13 alternating with the same number of grooves.

The chromosome investigations in this species are made from germinating pollen grain smears growing in natural mucilage and that containing colchicine and sulfanilamide and also during the study of microsporogenesis. From all these studies it can be stated that the haploid chromosome number in this species is 14 beyond doubt. During microsporogenesis 14 pairs are observed at diakinesis which means that the diploid number is 28 and again 14 chromosomes are clearly seen at the two poles prior to 2nd meiotic division. But the chromosomes are much condensed and consequently not quite suitable for morphologic study. On the other hand in pollen smears during the division of the body nucleus, the chromosomes appear elongated in strong contrast to their appearance at meiosis and being haploid in number in the enough space of the body cell afford extremely clear pictures both as regards their number and morphology. Photo 17 Pl. IV shows the view of chromosomes of the dividing body nucleus at metaphase in a normally germinating grain, the 'spindle gametophyte' in this particular case instead of being fixed longitudinally as is usually the case is fixed at one of the poles. In the centre the dark sphere is the stalk nucleus. The chromosome setup of this grain is drawn in Fig. 19 where 14 chromosomes, ready for splitting into daughters, are clearly counted. Photo 18 (lower) Pl. IV similarly depicts 14 chromosomes spread out in a flat plate at normal metaphase. Similarly 14 chromosomes are clearly counted in a large number of grains treated with colchicine and sulfanilamide. One of these treated with sulfanilamide showing 14 chromosomes scattered because of absence of spindle is seen in Fig. 20. The same is also shown in Photo 19 Pl. IV.

The karyotype—

The chromosomes are long. Ten chromosomes possess median, slightly sub-median or distinctly sub-median kinetochore. Being more or less of the same size and with slight differences in the position of their fibre-attachment regions they are not sharply distinguished from each other except the three chromosomes VIII, IX, X which are distinguished by other peculiarities. Chromosome VIII (Fig. 20) possesses a secondary sub-terminal constriction which becomes

very conspicuous at anaphase when the chromosome undergoes stretching (Photo 18 upper, Pl. IV). Chromosomes IX, X each possesses a satellite Fig. 20, Photo 19 Pl. IV. Chromosome X possesses slightly sub-median kinetochore and chromosome IX distinctly sub-median kinetochore. Besides, the former is larger of the two. The satellite in both the chromosomes is at the end of the relatively shorter arm. In Photo 17 which is also shown in Fig. 9, the satellite on chromosome X is not come within the focus. In the other grain shown in Photo 18 (below) the same chromosome on the extreme upper region is seen bearing the satellite.

The remaining 4 chromosomes of the complement XI, XII, XIII, XIV possess sub-terminal fibre attachment region.

Diploid grains—

The diploid grains are observed scattered among haploid ones in the smear preparations. They occur to the extent of 2-3% of the total output of grains. The details regarding their external appearance, size and mode of formation have already been discussed.*

The '*spindle gametophytes*' that escape from these during their germination are much larger than the haploid '*spindle gametophytes*'. The average size of the haploid ones is $65\ \mu \times 30\ \mu$ as against $80\ \mu \times 45\ \mu$ of the diploid ones but there is a variation in size of both. On the whole, the diploid gametophytes are about double the size of the haploid ones as seen in Photo 20 Pl. IV.

The chromosome complement of these diploid gametophytes is 28 as seen in the division of the body nucleus. This is shown in Fig. 21 which is drawn from a diploid grain growing in natural mucilage. The chromosomes are arranged at the equator of the spindle but some of these are slightly pressed out of position during the preparation of the smear.

Somatic pairing—

The phenomenon of somatic pairing observed previously in the diploid grains of *E. intermedia* is also noticeable here. Chromosomes marked aa, bb, cc, dd, etc., in Fig. 21 represent pairs of similar chromosomes together and in some cases with their arms more or less parallel.

The chromosomes in the diploid grains behave in the usual fashion during the further process of mitosis and the two male nuclei are organised in the same way as in the germination of an ordinary haploid grain. Thus each male nucleus formed in the diploid grain contains 28 chromosomes. The

* Mehra P. N.—Method of formation of Diploid pollen and the development of male gametophyte in *Ephedra saxatilis* Royle Ind. Bot. Soc. Iyengar Mem. Vol. 1946.

two male nuclei in the diploid grains, as in the haploid ones, are markedly unequal in size with the male nucleus towards stalk nucleus end invariably bigger than the other. The size of the respective male nuclei is approximately double in the diploid grains compared to the haploid ones.

Again the size of the stalk and tube nuclei in the diploid grain is double the size of these in the haploid one (Photo 20 Pl. IV).

Ephedra sinica Stapf.

E. sinica is so far known to be dioecious Florin⁷. The plants that have grown out of the seeds of this species received from United States Department of Agriculture are of three types, either male or female or monoecious. The monoecious plants bear both the strictly male and female cones as well as cones which are bisexual on the same individual. In the bisexual cones the male flowers are below while the ovules above. The monoecious individuals otherwise agree in all respects with typical *E. sinica* plants.

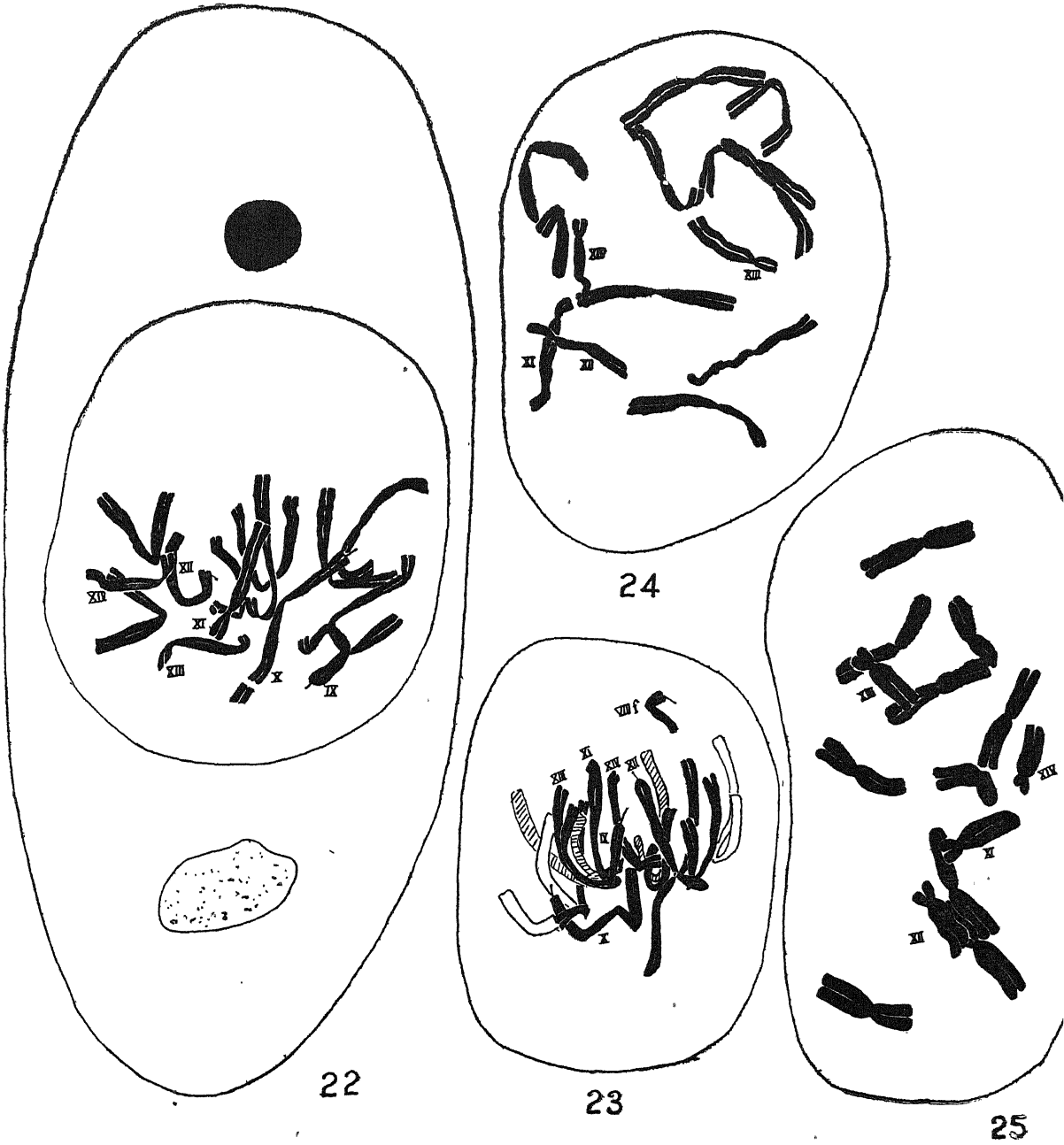
The number of ridges and grooves in the exine of the pollen grains in this species is very few, only 4-7, compared to those in other species investigated.

The chromosome investigations have been made only from the germinating pollen smears, normal and those treated with colchicine and sulfanilamide. Smears of germinating pollen were made from (i) purely male plants and (ii) from monoecious plants—the pollen in this case being taken from bisexual cones as well as from purely male cones separately. The pollen in both male and monoecious plants is fertile. No visible difference could be detected in the karyotypes of pollen grains from these different sources.

The haploid chromosome number is definitely 14. This is seen in Fig. 22 (drawn from grain shown in Photo 21 Pl. V) in which the chromosomes are spread in the equatorial plate in normal mitosis of the body nucleus, in colchicine treated preparation (Fig. 24) and sulfanilamide preparation (Fig. 25 and Photo 23 Pl. V). In sulfanilamide preparation the chromosomes have much thickened due to the action of the chemical and have brought out the position of the kinetochores very prominently.

E. sinica (22-25)

22. 'Spindle gametophyte' with chromosomes at metaphase in normal division of body cell nucleus. Grain grown in natural mucilage.
23. Chromosomes at metaphase within body cell of a grain grown in natural of secretion showing a cut off fragment lying outside the spindle region.
24. Scattered chromosomes within body cell of a grain germinated in 0.2% colchicine containing secretion.
25. Scattered chromosomes within body cell of a grain showing sensitive reaction of chromosomes to sulfanilamide. Chromosomes condensed.



The karyotype—

Ten chromosomes possess median, slightly sub-median or distinctly sub-median kinetochore. They are elongated. These chromosomes because of almost same length and similar position of kinetochore or slight and gradual differences both in size of chromosomes as well as in the position of their kinetochore cannot be sharply marked from one another except the three chromosomes marked VIII, IX and X in Fig. 23 which shows the chromosomes arranged at the equator during normal mitosis. These three chromosomes possess a satellite each in one of the arms. Chromosome IX, X possess sub-median kinetochore and a satellite is borne at the end of the shorter arm in each. Besides chromosome X is the larger of the two and also possesses a secondary sub-terminal constriction in the longer arm well marked in the preparation from which Fig. 22 is drawn. That chromosome VIII is also a Sat-chromosome is deduced from the fact that in the normally germinating '*spindle gametophyte*' (Photo 22 Pl. V) whose body cell is shown in Fig. 23, fourteen chromosomes are visible at the equator of the metaphase and a small fragment marked 'VIII^f' bearing a satellite is observed very much outside the spindle region. This in all probability is cast off from an ordinary Sat-chromosome. This is the only case where a fragment is noticed to be cast off in the body nucleus mitosis in the species.

The remaining four chromosomes marked XI, XII, XIII, XIV in the different Figs. bear sub-terminal kinetochore and can easily be distinguished in the chromosome complex. Of these 'XI' is the largest and 'XII' is characterised by the possession of a satellite at the end of the longer arm Fig. 23.

Thus out of 14 chromosomes, 4 are Sat-chromosomes and one of these four also possesses a secondary sub-terminal constriction. It may be remarked that satellites are not very pronounced and appear as thin prolongations which possess rather minute knobs at the end.

Diploid grains—

No truly diploid grains are observed from both male and monoecious plants. Only in one case a twin pollen grain was noticed in which two normal grains had not yet separated from one another at one end. At this region of union the intervening wall had not been laid and their interior was thus continuous. During germination, when the exine was cast off from this twin grain, a '*twin gametophyte*' emerged in which each of two parts was complete in all respects as in an ordinary pollen but both the parts were internally continuous at one of the poles.

Ephedra likiagensis Florin.

There are 13-14 ridges and grooves in the exine of the pollen grain of this species.

The chromosome number is investigated only from the study of the germinating pollen smears. The haploid number is 14 beyond doubt. In Fig. 26 is shown a 'spindle gametophyte' with normal mitosis (same also seen in Photo 24 Pl. V) and the 14 chromosomes spread in a metaphase plate observed from the polar view. In this particular case the spindle is laterally directed instead of being parallel to the long axis of the grain. Also the stalk nucleus is lateral in position on the upper side instead of being towards one of the poles. It is an interesting feature in all the species of the genus that the long axis of the spindle is invariably directed towards the direction of the stalk nucleus. Similarly Fig. 27 shows the body cell of a grain treated with colchicine shown in Photo 25 Pl. V and 14 chromosomes scattered after the loss of the spindle are clearly observed. Also in Figs. 28, 29 (the former also reproduced in Photo 26 Pl. V which shows the progressive condensation of the chromosomes accompanied by an increase in thickness and decrease in length due to the sensitive reaction of the chromosomes to colchicine) 14 chromosomes in each within the boundary of the body cell can be easily counted.

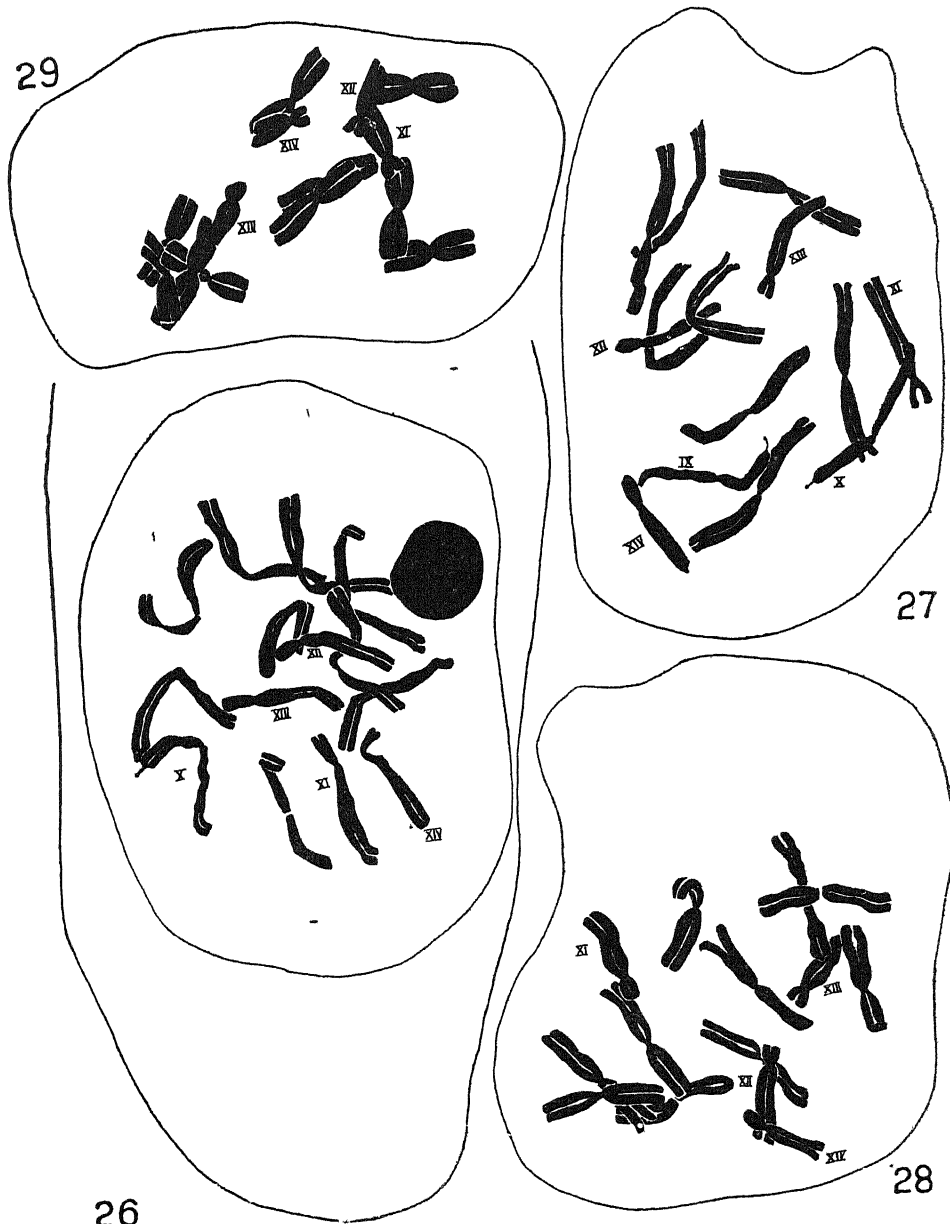
The karyotype—

Ten of the 14 chromosomes possess kinetochores median, slightly sub-median or distinctly sub-median in position. These chromosomes are elongated and majority of them are more or less similar in size. Also the position of kinetochore is not markedly different in many cases. It is either median or slightly sub-median with not much difference in the length of the two arms, and when distinctly sub-median the difference is gradual in different chromosomes. Consequently the individual chromosomes are not easily identifiable excepting chromosomes IX & X both of which possess a satellite each, Fig. 27 and Photo 25 Pl. V. In each of these Sat-chromosomes the kinetochore is sub-median, more markedly so in X than in IX and a satellite in each is present at the end of the relatively shorter arm.

The remaining four chromosomes marked XI, XII, XIII, XIV in Figs. 26-29 possess sub-terminal kinetochores and belong to the 'f, g' category of *E. foliata*. These become very clearly marked in Figs. 28 & 29 where condensa-

E. likiagensis (26-29)

26. 'Spindle gametophyte' with chromosomes at normal metaphase plate. Stalk nucleus lateral in the upper region, tube nucleus not shown.
 27. Scattered chromosomes within body cell of a grain grown in 0.2% colchicine containing secretion.
 28, 29. Progressive condensation of chromosomes due to the sensitive reaction to colchicine.



tion of chromosome arms has occurred due to sensitive reaction of chromosomes to the drug colchicine, thereby bringing kinetochore constrictions into great prominence—an effect which has previously been seen in the case of *E. sinica*, to have been brought about by sulfanilamide. Chromosome XI amongst these is the largest and the rest three comparatively smaller.

No diploid grains have so far been observed in this species.

SUMMARIZATION OF THE RESULTS.

Abbreviations used: S. C. Secondary constriction possessing chromosome; Sat.—Satellite bearing chromosome.

Name of the Species.	Haploid chromosome number.	Analysis of the complement.		Total number of Sat. chromosomes and those with secondary constrictions.	Diploid grains.
		Median and Sub-median kinetochore chromosomes.	Sub-terminal kinetochore chromosomes		
Scandentes Stapf.					
<i>E. foliata</i> v.r. <i>ciliata</i> .	7	5 (1 S.C.)	2 (1 S.C.)	2 S.C.	Present.
<i>E. altissima</i> var. <i>Algerica</i> .	14	10 (3 S.C., 4 Sat.)	4 (1 S.C.)	4 S.C., 4 Sat.	Present.
Pachycladae Stapf.					
<i>E. intermedia</i> var. <i>tibetica</i> .	14	10 (1 bearing Sat. at each end & 1 S.C.)	4	1 Sat & 1 S.C.	Present.
Leptocladae Stapf.					
<i>E. gerardiana</i> ..	7	5 (2 at).	2 (1 Sat.)	3 Sat.	Not investigated
<i>E. saxatilis</i> ..	14	10 (2 Sat & 1 S.C.)	4	2 Sat & 1 S.C.	Present.
<i>E. sinica</i> ..	14	10 (3 Sat of which 1 also possesses S.C.)	4 (1 Sat.)	4 Sat. of which 1 also S.C.	Not present.
<i>E. likiangensis</i> ..	14	10 (2 Sat.)	4	2 Sat.	Not present.

DISCUSSION AND CONCLUSIONS.

From a critical study of the above table the following conclusions emerge out for the various Tribes.

Tribe Scandentes Stapf.

1. Polyploidy has occurred during the evolution of the species.
2. Chromosome constitution of *E. altissima* does not represent the exact duplication of the karyotype of *E. foliata* and the former, therefore, is not an auto-tetraploid of the latter inspite of strong resemblances of the two species

in vegetative parts. There are 4 Sat-chromosomes in *E. altissima* but none in *E. foliata*. Again in *E. altissima* there are 4 chromosomes which bear secondary constrictions (3 belonging to median or sub-median kinetochore category and one to sub-terminal kinetochore category) while in *E. foliata* there is certainly one but probably two chromosomes with secondary constriction of which the former belongs to median kinetochore category and the other to sub-terminal kinetochore category. *E. altissima* seems to be an allo-tetraploid.

3. Broadly speaking the 'Basic Karyotype' seems to consist of 7 chromosomes of which 5 chromosomes possess median or sub-median kinetochore and 2 with sub-terminal kinetochore. One such set is present in the haploid complement of *E. foliata* and 2 such sets in the haploid complement of *E. altissima*.

4. Diploid grains are formed in small quantities besides the haploid ones.

Tribe Leptocladae Stapf—

1. Polyploidy has occurred during the evolution of species within the tribe.

2. Detailed constitution of the karyotype in the polyploid (tetraploid) species is different from one another as shown by the difference in the number of Sat. and secondary constriction bearing chromosomes.

3. None of the 3 tetraploid species *E. saxatilis*, *E. sinica*, *E. likiagensis* represents in its karyotype two exactly similar sets. All the three are, therefore, allo-polyploids.

There appears to be broadly speaking a 'Basic Karyotype' for the members of the tribe consisting of 5 chromosomes with median or sub-median kinetochore and 2 with subterminal kinetochore and whenever tetraploidy has occurred this fundamental basic set is represented twice over.

5. Diploid grains in a small percentage besides the haploid ones are present in one species *E. saxatilis*. In the other two *E. sinica* and *E. likiagensis* whose pollen grains have been investigated they are absent.

Chromosome number in the genus Ephedra :—

Next comes the consideration of the chromosome number* in the species of the genus *Ephedra* so far worked out. Below is given the list of these upto date together with the name of the authors. Where the diploid chromosome number is investigated it is indicated by the letter 2n.

*This list has been prepared from Tischler²² and the species investigated in the present paper added.

<i>Section.</i>	<i>Species.</i>	<i>Chromosome number.</i>	<i>Author.</i>
Alatae	.. <i>E. trifurca</i>	.. 12	Land 1904
Pseudobaccatae (Scandentes).	<i>E. foliata</i> var. <i>ciliata</i> .	7 } 2n=14 }	Mehra, 1934
	<i>E. altissima</i>	.. Ca 12	Berridge 1909
		2n=28?	Resende 1937
		14	Mehra
	<i>E. fragilis</i> var. <i>campylopoda</i> .	6?	Herzfeld 1922
	<i>E. campylopoda</i>	7	Geitler 1929
(Pachycladae)	.. <i>E. intermedia</i> var. <i>tibetica</i> .	14 } 2n=28 }	Mehra
(Leptocladae.)	.. <i>E. major</i>	.. 7	Geitler 1929
	<i>E. nebrodensis</i> var. <i>procera</i> .	2n=14	Florin 1932
	<i>E. equisetina</i>	.. 2n=14	Florin 1932
	<i>E. gerardiana</i>	7	Mehra
	<i>E. saxatilis</i>	14 } 2n=14 }	Mehra
	<i>E. sinica</i>	.. 2n=28? 14	Resende 1937 Mehra
	<i>E. likiagensis</i>	.. 14	Mehra
	<i>E. distachya</i>	.. 12	Berridge and Sandey 1907
	<i>E. helvetica</i> .	.. 8?	Jaccard 1894
	<i>E. distachya</i>	.. 2n=28 2n=28?	Florin 1932 Resende 1937
	Antisyphiliticae .. <i>E. americana</i>	7	Florin 1932
	<i>E. andina</i> .	2n=14	Resende 1937

It is seen from the above table that the haploid chromosome number in the different species investigated is 7 or 14. The discrepancies in this respect were in *E. altissima* where Berridge reported the haploid number to be somewhere near 12 and Resende doubtfully 14 but conclusively shown by the author to be 14, in *E. fragilis* var. *campylopoda* where Herzfeld described the number 6 with uncertainty and shown to be 7 by Geitler, in *E. distachya* where Berridge and Sanday reported the number to be 12 but shown to be 14 by Florin. Thus according to the revised studies out of 15 species studied so far, seven possess 7 as the haploid number, six possess 14 haploid chromosome number while in one, namely, *E. helvetica* the haploid number is reported to be doubtfully 8 and in the other, namely, *E. trifurca*, the haploid number is described as 12.

Out of these species investigated only one namely *E. trifurca* belongs to the section *Alatae* while all the rest belong to the section *Pseudobaccatae*. Evidently, therefore, the basic chromosome number for the section *Pseudobaccatae* at least is 7. It is highly probable that *E. helvetica* which belongs to this section and which is the only discrepancy will on reinvestigation show its chromosome number to be 7.

As regards *E. trifurca* Land's investigation on the heterotypic and homotypic division of the mother cells led him to believe the haploid chromosome number to be 12. He himself states at one place that the chromosomes as they lie at the equator at metaphase are "short and thick, closely massed and can be counted with extreme difficulty" although he makes a definite statement that the chromosome number for the species is 12. In view of the fact that the majority of the species of the genus investigated have shown the chromosome number to be 7 or a multiple of 7 and taking into consideration that counts were made from the preparations which did not afford satisfactory counts as stated by the author himself, one is led to doubt 12 as the chromosome number for *E. trifurca*. Perhaps Land was carried away by the prevailing idea then that Gymnosperms mostly possess 12 chromosomes. The only consideration is that *E. trifurca* belongs to the section *Alatae* while the species in which the basic chromosome number is established to be 7 all belong to *Pseudopaccatae*. While there is certainly a possibility that the species belonging to a different section may possess a different basic number it seems more probable that a reinvestigation of this species would reveal the number to be 14 rather than 12.

Taking all the data into consideration both from the present investigation and those of the previous workers the following conclusions are obvious.

1. The basic chromosome number for the genus *Ephedra* is 7.
2. Polyploidy has occurred within the genus during the evolution of the species and that it has been frequent is shown by the fact that it is observed in 6 out of 15 species investigated. Previously only one species was known to possess 14 chromosomes in the haploid set while 5 more belonging to the two tribes are added to the list from the present investigations. Polyploidy is not of high order. It seems to be restricted to tetraploidy only.
3. Aneuploidy does not seem to have played any part in the evolution of the species in the genus.
4. Basic Karyotype—A study of the Karyotype has been undertaken in the present thesis on 7 species of the genus all belonging to Pseudobaccatae. It is observed that in species with a single basic complement, *i.e.*, 7 as the haploid chromosome number (*E. foliata* and *E. gerardiana*) there are two chromosomes with sub-terminal fibre-attachment region and five with median or sub-median fibre-attachment.

In every species which possesses double the basic number or 14 chromosomes in the haploid complement, (*E. altissima*, *E. intermedia*, *E. saxatilis*, *E. sinica* and *E. likiangensis*) there are invariably 4 chromosomes with sub-terminal kinetochore and 10 with median or submedian kinetochore. It is obvious that in these that the basic set is represented twice over.

It may be stated, therefore, that the 'Basic Karyotype' in the genus (at least the section Pseudobaccatae) is characterised by the possession of 2 chromosomes with sub-terminal kinetochore and 5 with median or sub-median kinetochore. It appears that this basic complex has not undergone marked changes during species differentiation. Of course variations of detailed nature like trabants, secondary constrictions and gene changes etc., have occurred in the individual chromosomes of the 'Basic Karyotype' in the evolution of different species. This is well illustrated by a comparison of two species *E. foliata* and *E. gerardiana*. While no satellites are observed in *E. foliata*, one at least or probably two chromosomes bear secondary constrictions while in *E. gerardiana* there are 3 Sat. Chromosomes and none with secondary constrictions.

Thus polyploidy coupled with variations of detailed nature in the individual chromosomes of the 'Basic Karyotype' have both played part in the evolution of the species in the genus.

5. One very striking feature noticed in the study of chromosome morphology of the various species is that every species possesses either satellites or secondary constrictions or both in some of its members. No species is devoid of these. In the light of recent researches which point to the association of nucleoli formation with chromosomes bearing satellites or secondary constrictions, these observations are quite significant.

6. Diploid gametophytes (from diploid pollen grains).

Diploid grains are observed to be present in 4 out of the six species studied from this aspect representing 3 of the 4 tribes of *Pseudobaccatae*. In *E. foliata* they do not occur commonly but neither by any means rarely. In its closely allied relative *E. altissima* they are fairly abundant, to the extent of 5% of the total output of grains. In *E. intermedia* and *E. savatilis* they occur to the extent of 2-3%. In *E. sinica* and *E. likiangensis* they are absent.

The mode of formation of diploid grains has already been studied in detail in *E. savatilis* from smears of pollen mother cells. It has been shown that both the haploid and diploid microspores may be formed in the same microsporangium. In fact some mother cells may produce normal tetrad of 4 haploid microspores, others may form two haploid and one diploid microspore and still others only two diploid microspores. Again while some microsporangia may thus produce a mixture of haploid and diploid microspores, others may form haploid microspores only.

So far as the writer is aware, the occurrence of diploid grains besides the haploid ones are not known to occur in any other gymnosperm. The only case known to the writer in nature is in an Angiosperm *Calycanthus fertilis* (Schurhoff¹⁸).

The 'spindle gametophytes' emerging from such diploid grains are larger in size than those liberated from haploid grains in the same species. The chromosome constitution of the diploid grain is studied in all the 4 species from the division of its body nucleus. In *E. foliata* where the haploid grains show during this division 7 chromosomes, 14 are seen in the diploid grains while in all the rest 3 species where 14 chromosomes are observed in the haploid grains, 28 are observed in the diploid ones. In all these cases since exactly the same complement is doubly represented in the diploid grains (having been derived from the two nuclei of the same mother cell), these grains are auto-diploid.

Somatic pairing—

Somatic pairing of chromosomes is observed in the diploid grains in *E. saxatilis* in the mitotic figures of the body nucleus. The corresponding chromosomes in the doubled complement are observed to lie more or less parallel and close to one another indicating a sort of attraction for the corresponding members. In *E. foliata* where the diploid grains were treated with colchicine, resulting in the inhibition of the spindle, the corresponding chromosomes are still observed to lie near one another. In *E. intermedia* indications of somatic pairing seem to be present even in the haploid grains. Perhaps the two sets that constitute the haploid complement of *E. intermedia* are closely similar and because of that the corresponding chromosomes tend to remain near one another. In the diploid grains the exactly similar chromosomes lie close together at the metaphase plate in the mitosis of the body nucleus as in *E. saxatilis*.

Somatic pairing is known to occur characteristically in Diptera where the corresponding homologues in the diploid complement show a very regular paired arrangement. Among plants the phenomenon is known only in a few cases. It is reported in polyploid *Dahlias* at mitosis by Lawrence and in tetraploid nuclei at mitosis in *Sorghum* by Huskins and Smith and in *Spinacia* by Stomps—the tetraploid nuclei in all probability having arisen in the diploid tissue by failure of daughter chromosomes to separate (Darlington⁵).

The germination of the diploid grains resembles in every respect that of the haploid ones in the same species. The diploid set in every case splits at metaphase and the diploid number of daughter chromosomes proceed toward the two poles to organise the two male nuclei. Thus the constitution of the male nuclei formed from the diploid grains is also $2n$ compared to that formed from the haploid ones which is n , in these four species. Within the same species even the details of the formation of the male nuclei in diploid grains is the same as in the haploid ones. Thus in *E. intermedia* and *E. saxatilis* where the two male nuclei formed in the haploid grains are markedly unequal in size (the one towards the stalk nucleus end being larger), the same feature is observed in the diploid grains. Further, the relative size of the male nuclei in the diploid gametophyte is about double the size of the male nuclei at the corresponding stages in the haploid gametophyte in the same species. Similarly the stalk and the tube nuclei in the diploid gametophyte are about double their respective size in the haploid gametophyte of the same species.

The next question is whether the formation of diploid grains in these species is inherent or environmental?

In the case of *E. foliata* the case is relatively simple. This species is a native of the Punjab and under natural conditions of its growth is observed to form diploid grains besides the haploid ones. The same sporangium may produce both types of grains. There is no question here of any change in environment and this may, therefore, be regarded as a feature inherent to the species. When it is natural for one species of the genus, the same phenomenon can reasonably be so in other cases as well if it occurs. But the other 3 species are exotics and it may be argued that the formation of diploid grains in these may be the result of altered environmental conditions which are different in the Punjab plain from those prevailing in their natural habitat*. This seems improbable but the final answer to the criticism can come only from the study of the problem from plants growing in a natural state in their own home. But in the absence of that and when we take into consideration that the similar phenomenon under natural circumstances occurs in *Ephedra foliata* it seems highly probably that it may be characteristic also of *E. altissima*, *E. intermedia* and *E. saxatilis* to produce diploid grains in the normal course of their life cycle particularly when we bear in mind that these species grow and reproduce as vigorously here as in their natural home.

Since the production of diploid grains is observed to occur in 4 out of 6 species studied, it looks as if this phenomenon is fairly wide-spread within the genus. Investigation on other species in this direction is very desirable.

Chromosome number in the Gnetales—

The other two genera belonging to the Gnetales are *Welwitschia* and *Gnetum*. The former is a monotypic genus with the only species *W. mirabilis* and its haploid chromosome number was stated by Pearson¹⁵ to lie between 22-26 probably 25 from some stages in the heterotypic division in the microspore mother cells. Later Florin⁶ reported the diploid number to be 42 from the root tips. Fernandes (*vide* Tischler²²) confirmed the diploid number to be 42 for the species. This number also represents a multiple of the basic number 7 established for *Ephedra*. It seems highly probable that the basic chromosome number in the entire group may be 7 (Florin⁶). But evidence in this direction is not forthcoming from the genus *Gnetum* in which the chromosome number of only two species is reported. Pearson¹⁶ stated the haploid number (from stages in heterotypic division of microspore mother cells) to

**E. altissima* is a native of North West Africa met with from Morocco to Tunis and in the mountainous region on both sides of Atlas. *E. intermedia* grows in Kashmir, North-West Punjab hills, Lahul, Spiti in Western Tibet, North East Afghanistan, Baluchistan, etc., and *E. saxatilis* in Simla, Aunsar, Kamaon, Zaskar and Southern Tibet at high elevations.

be probably 12 but was doubtful. Coulter⁴ just made a passing reference from some stages in microsporogenesis that the haploid and diploid number is 12 and 24 respectively for *Gnetum gnemon* without giving any drawings in support of his assertion. It is very much desired that the chromosome number of the members of this genus be thoroughly worked out by investigators to whom the material is readily accessible.

In view of the great morphological and embryological diversities of the 3 genera of the Gnetales it seems improbable that the same 'Basic Karyotype' which seems to be characteristic of the genus *Ephedra* would be represented in the other two genera as well.

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EXPLANATION OF PLATES

All photos x about 1100 except where specified.

E. foetida, Pl. I, 1-4

1. Same as fig. 3 x about 1020.
2. Scattered chromosomes in haploid grains grown in mucilage secretion containing 0.5% sulfanilamide.
3. Haploid and diploid grains side by side growing in secretion containing 0.5% sulfanilamide.
4. Same as fig. 6.

E. altissima Pl. II 5-9

5. Same as fig. 9.
6. Haploid and Diploid grain side by side grown in natural secretion Both at metaphase.
7. Diploid gametophyte at anaphase in normal mitotic division.
8. Haploid and diploid gametophytes side by side grown in natural secretion. Both have formed male nuclei.
9. Same as fig. 10.

E. intermedia Pl. III, 10-14

10. Same as fig. 14.
11. A haploid and a diploid gametophyte side by side grown in natural secretion, both at metaphase.
12. A haploid gametophyte grown in secretion containing 0.5% sulfanilamide. Chromosomes scattered.
13. A diploid gametophyte grown in 0.5% sulfanilamide containing secretion. Not all the 28 scattered chromosomes come within the focus.
14. A haploid and a diploid gametophyte growing side by side in 0.5% sulfanilamide containing secretion.

E. Gerardiana Pl. IV, 15-16

- 15, 16. Haploid chromosome complement in a cell of the female gametophyte. Seven chromosomes counted x about 1020.

E. saxatilis Pl. IV, 17-20

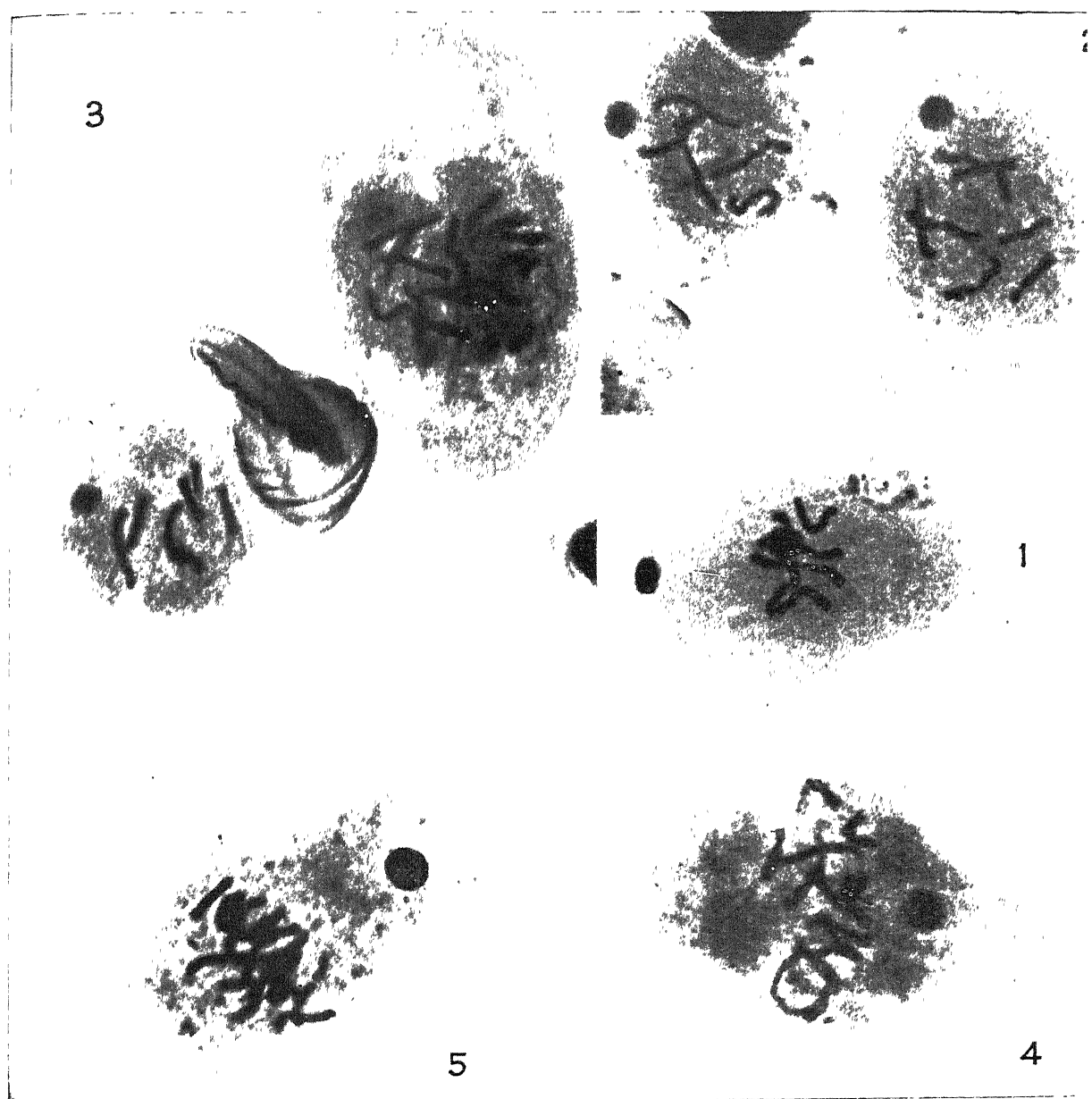
17. Same as fig. 10 x about 1020
18. Two haploid gametophytes germinating in natural secretion. The one above at late anaphase while that below at metaphase plate. x about 1020.
19. Same as fig. 20.
20. A haploid and a diploid gametophyte growing side by side in natural secretion.

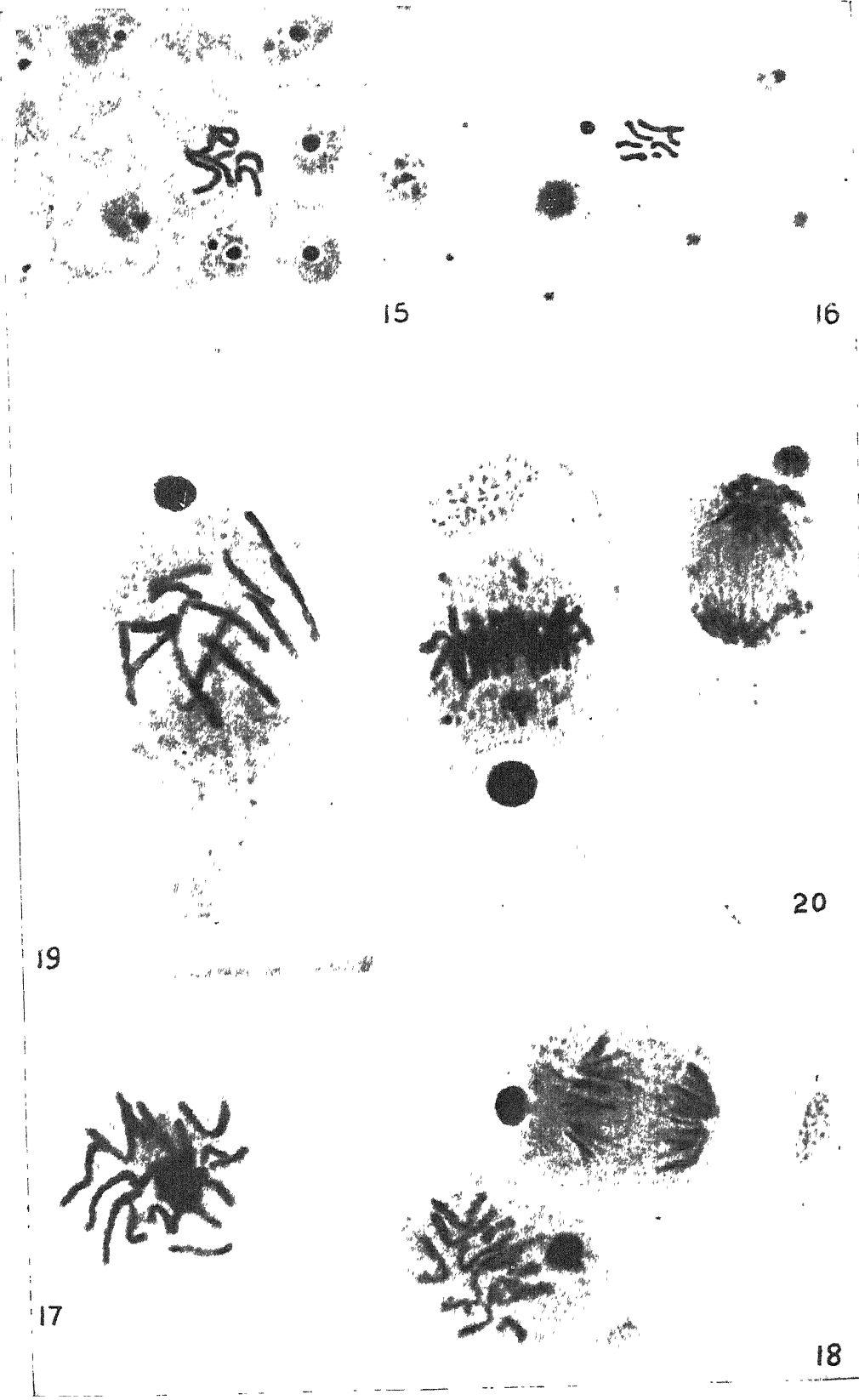
E. sinica Pl. V. 21-23

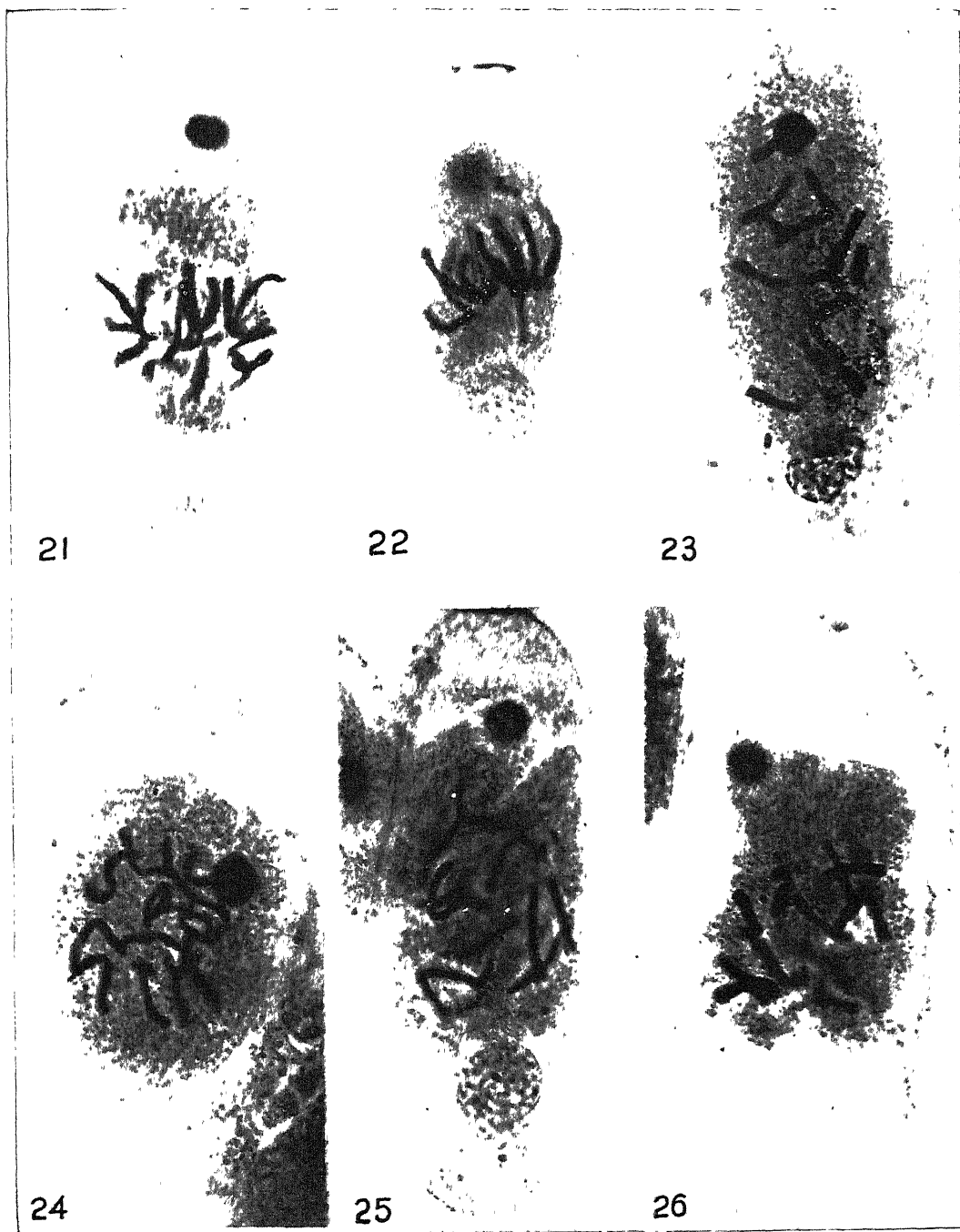
21. Same as fig. 22.
22. Same as fig. 23.
23. Same as fig. 25.

E. likiangensis Pl. V. 24-26

24. Same as fig. 26.
25. Same as fig. 27.
26. Same as fig. 28.







STUDIES ON THE RANJAN X-RAY MUTANT WHEATS

1. Genetical analysis of the eleven variants

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(With four tables)

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ABSTRACT

The eleven new mutant wheats obtained by exposing seedlings to X-rays (reported earlier) were studied through seven generations.

Of the eleven mutants, eight, *i.e.*, R1, R2, R5, R7, R8, R9, R10 and R11 remained true to their original forms, but three others, *i.e.*, R3, R4 and R6 continued breaking especially as regards the character of the awns.

Variants of R4 became fixed in the X3 generation while the variants obtained from R3 and R6 continued breaking for generations; only in later generations the disturbances due to the X-rays appeared to be dying out and the strains becoming fixed. In the sixth generation out of 18 strains of R3 only four and out of 25 strains of R6 only three continued breaking.

The sudden appearance of the variants and their subsequent history leads one to conclude that due to the impact of electrons of X-ray radiations on the protein molecules of the genes, changes in the molecular constitution of some of the genes may have taken place, resulting in new adjusted states. In certain cases these adjusted states were reached within one generation such as in R1, R2, R5, R7, R8, R9, R10 and R11 while in others such as in R3, R4 and R6 there were varying degrees of prolonged disturbances ultimately reaching the new adjusted states in the 5th and 6th generations, while in the progenies of strain Nos. 302, 309, 315 and 316 and in the progenies of strain Nos. 604, 610 and 619 the adjusted state is not reached even in the X7 generation.

INTRODUCTION

De Candolle believed that the wheat originated in the valley of the Tigris and Euphrates. Recently Vavilov (1926, 1927, 1928; Vavilov and Bukinich, 1929) after extensive studies of the cultivated plants came to the conclusion that the origin of the group of soft wheats which include the bread wheat (*Triticum vulgare*) is in the regions adjoining Northern India, South Western Afghanistan and Southern parts of mountainous Bokhara. This conclusion is based on the fact that a great number of dominant characters in *T. vulgare* are found in these regions.

As regards the origin of wheat, earlier workers held the view that all the races of cultivated wheats were derived from a single wild ancestor *Triticum aegilopoids*. Fabre (1855), however, cultivated the plant *Aegilops ovata* for 20 years and observed that in succeeding generations it became more and more

wheat like and concluded that the wild grass *Aegilops ovata* was the prototype of the present day wheat; later workers showed that *A. ovata* is a naturally occurring hybrid. The majority of botanists, however, now agree that the wheats are polyphyletic and that at least two different species are concerned in their origin—*Triticum aegilopoids* and *T. dicoccoides*.

Percival (1921) thinks that *T. vulgare* is a vast collection of mutants and hybrids which are regarded as having originated from the crossing of *T. dicoccoides* with one or two species of *Aegilops*.

The wheats under the modern classification are classified in four groups: Group I—Einkorn; Group II—Emmer; Group III which include only one wild species, *T. Timopheevi*; and Group IV—Vulgare. Sakamura (1918) working with root tips found 14 chromosomes in group I, 28 chromosomes in group II and 42 chromosomes in group IV. Group III also contains 28 chromosomes. These numbers have been confirmed both in haploid and diploid generations by several workers.

Recently various artificial devices have been employed for producing new mutants. Muller (1927) for the first time reported X-rays as an effective method for producing new mutants. Goodspeed and Avery (1934) obtained 14 types from a single X-rayed female gamete of *Nicotiana tabacum*. Delaunay (1930) X-rayed the ears of *T. vulgare* and got 8 variant types. Sapegin (1935) found that X-rays produced changes in the external morphology of *Triticum durum* and a few F₁ plants studied cytologically showed abnormalities. In *T. vulgare* he (1936) found a large number of deviating types characterised by various chromosomal abnormalities. The F₂ showed a much less wide range of variations than in F₁. Stadler (1928, '29) showed that the treatment with X-rays and radium causes large increase in mutant frequencies in maize, barley and wheats.

EXPERIMENTAL METHODS AND RESULTS

With a view to explore the possibilities of producing new economic variants, irradiation with X-rays were tried in this laboratory. It was in 1938 that through the courtesy of Dr. S. B. Singh, the then Dy. Director of Agriculture, U.P., pure strains of I.P. 52 were obtained. These were exposed to hard X-ray treatment for varying durations at the seedling stage and then planted on the experimental grounds. While the control seedlings grew true to the form, the X-ray treated ones showed variations in random plots. These variations were found in very few plants and in all 11 earheads were picked which varied in external morphological forms from the original I.P. 52 (see

table 1). As the control set did not show any variations these new forms were naturally taken as mutants produced by X-ray treatment. A short note of the account has been published by Ranjan (1940). The present paper deals with the subsequent history of these new mutant types (now designated as Ranjan mutants Nos. 1, 2 etc. or in short as R1, R2 and so on) as seen through seven generations. In the year 1944, R9 was christened as "Vijaya" after Mrs. Vijaya Lakshmi Pandit. The work is for the sake of convenience divided into (a) Genetical (b) Cytological and (c) Physiological studies of the 11 types. The present paper deals with genetical studies of the 11 variants.

The seeds of each earhead of the 11 new strains along with the seed of one earhead of I.P. 52 were separately sown in small plots in the following year to see whether these new strains kept true to their new forms or not. The I.P. 52 of course kept true. The 11 mutants were now in X_2 stage, for the X_1 or the first filial generation was the first earhead after X-ray and the result of the seeds of these earheads and the formation of the subsequent earhead is of the X_2 generation. The external morphological study of the X_2 generation is as follows:—

Strain Nos. R1, R2, R5, R7, R8, R9, R10 and R11 showed no variation either in the colour of the glumes or the length of the awns, the only significant difference being in the sizes of the spikes. The X_2 showed in all cases larger earheads than the X_1 . This may be ascribed to the disturbing effect of the X-ray treatment. Nos. R3, R4 and R6 showed tendency to mutate but no data of this was kept. Only seeds from those earheads were taken which resembled the earheads in the parents in X_1 generation.

In the third year seeds so collected were sown in a different set of experimental plots. A study of the X_3 progeny showed that again Nos. R1, R2, R5, R7, R8, R9, R10 and R11 showed no variations while differences were noticed in R3, R4 and R6. This time the differing earheads in R3 and R6 were picked separately while in No. R4 only those earheads which resembled the parental form were picked.

In the fourth, fifth, sixth and seventh years, Nos. R1, R2, R5, R7, R8, R9, R10 and R11 kept true to the original form while R3, R4 and R6 kept on breaking. The whole scheme of 8 years experimentation is shown in tables 1, 2, 3 and 4.

ANALYSIS OF THE STRAIN NOS. R3, R4 AND R6.

As mentioned above the strain No. R3 (table 2) in the X_3 generation showed definite variations particularly in regard to the awns in the ears. Three types were segregated; (a) those without awns (or with awns less than $\frac{1}{2}$ cm. long) designated as 3A, (b) those with awns of intermediate length designated as 3B and (c) those with fully developed awns 3C. In the X_4 both 3A and 3B again showed variations, the former into awnless and longawned varieties and the latter into three categories, *viz.*, awnless, short awned and long awned; while 3C did not show any variations and bred true to the parental form. This strain was not shown in subsequent generations.

When the seeds of X_4 were being collected, the plants with white ears were separated from those with brown ears to note whether this character also showed random variations or not. Unfortunately, in the next generation during the harvesting season, owing to prolonged rains, most of the plants lodged and it was not possible to separate the plants on this basis. They were, therefore, only collected into 2 groups awnless, (including the short awned ones) and the awned. In the X_5 the number of plants in the strain that were breaking were counted and these numbers are given in the table underneath the character of the awns. The ratio between the awnless plants and awned plants is very variable in the different variants, the extremes being 1 : 0.1 and 1 : 16. All these variants were sown in 1944 and in 1945 the X_7 seeds were obtained. In this generation out of the 18 variants 14 bred true and only in 4 instances they further broke into awned and awnless plants or into brown and white eared plants. It appears that the different variants are gradually getting fixed. The number of plants in each variant which were still breaking are noted in the table.

Strain No. R4 (table 3) however, behaved quite differently. When the X_3 seeds were sown in the X_4 only 2 variants, awnless and fully awned, were obtained. But in the X_5 , X_6 and X_7 both of these bred true to form. These strains presumably got fixed earlier than is in the X_5 .

Strain No. R6 (table 4) behaved more or less similarly to strain No. R3, but in this case the colour of the ears was uniform throughout in all the strains. In the X_4 however, 6A, 6B and 6C showed variations into awnless, short awned and long awned variants. In X_5 also all the 9 variants thus obtained segregated into awnless (including short awned) and awned plants. In X_6 most of the variants got fixed leaving only three variants breaking.

That the cause cannot be chance cross fertilisation is proved by the fact that other mutants such as R1, R2, R5, etc. bred true and did not show any variants in later generations though they were identically sown side by side with these variants.

From the above data one gathers that in those cases where, as a result of X-ray treatment, changes have taken place in centres other than those responsible for awns, the strains have kept true, after the first initial changes, such as in R9, R10 etc.; while in those cases where changes in the genes responsible for awns have taken place, such changes have not kept true in all the cases, for instance R5 has kept true whereas R3, R4 and R6 kept on breaking in successive generations. One concludes that as a result of X-ray not only changes have taken place in random genes but that these have been of a complicated nature. For in the case of the colour changes of the glumes as also in the physiological make up (to be published later), the changes having once occurred got quickly stabilised to their new forms but in those cases of genes responsible for the development of awns, a disturbed state has continued for several generations in many cases. These latter prolonged disturbances may be called "the after effect" of X-ray. There is, however, a tendency for this disturbed state to die out resulting in the mutants to reach their stable forms as is evident from tables 2, 3 and 4. In all cases, however, it was noticed that the spikes of the X_1 were smaller than the parent, showing thereby that the physiological instability continued in the X_1 generation though many of the strains kept true to their new forms. In the X_2 however, the spikes of the true types reached their normal sizes.

As to the exact nature of these changes it is difficult to hazard. At the same time one will not be far wrong if one says that mutations must have taken place in the genes. If the gene is composed of complex protein molecules, then on the physico-chemical conception, as a result of the electrons impinging on the molecules, the nature of some of them could be changed thereby effecting the characteristics of the plant. A possible cytological explanation of the phenomenon of these mutations is also hazarded in the next paper of these series.

My thanks are due to Dr. N. L. Pal for his help in preparation of this work. I have also to thank Mr. A. P. Mehrotra for his occasional help.

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GENERATION

P

I P 52 AWNED
X-RAYED

	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11
X ₁	AWNED	AWNLESS	AWNLESS	AWNLESS	AWNLESS	AWNLESS	AWNED	AWNLESS	AWNED	AWNED	AWN
X ₂	TRUE	TRUE	BREAKING	BREAKING	TRUE	BREAKING	TRUE	TRUE	TRUE	TRUE	TRUE
X ₃	"	"			"		"	"	"	"	"
X ₄	"	"			"		"	"	"	"	"
X ₅	"	"			"		"	"	"	"	"
X ₆	"	"			"		"	"	"	"	"
X ₇	"	"			"		"	"	"	"	"

Table No. 1
Progenies of X-rayed I.P. 52 wheat

GENERATION

9

IP 52 AWNED
X-RAYED

R 3 A W N L E S S

R 3 ONLY A WINGLESS EARS PICKED

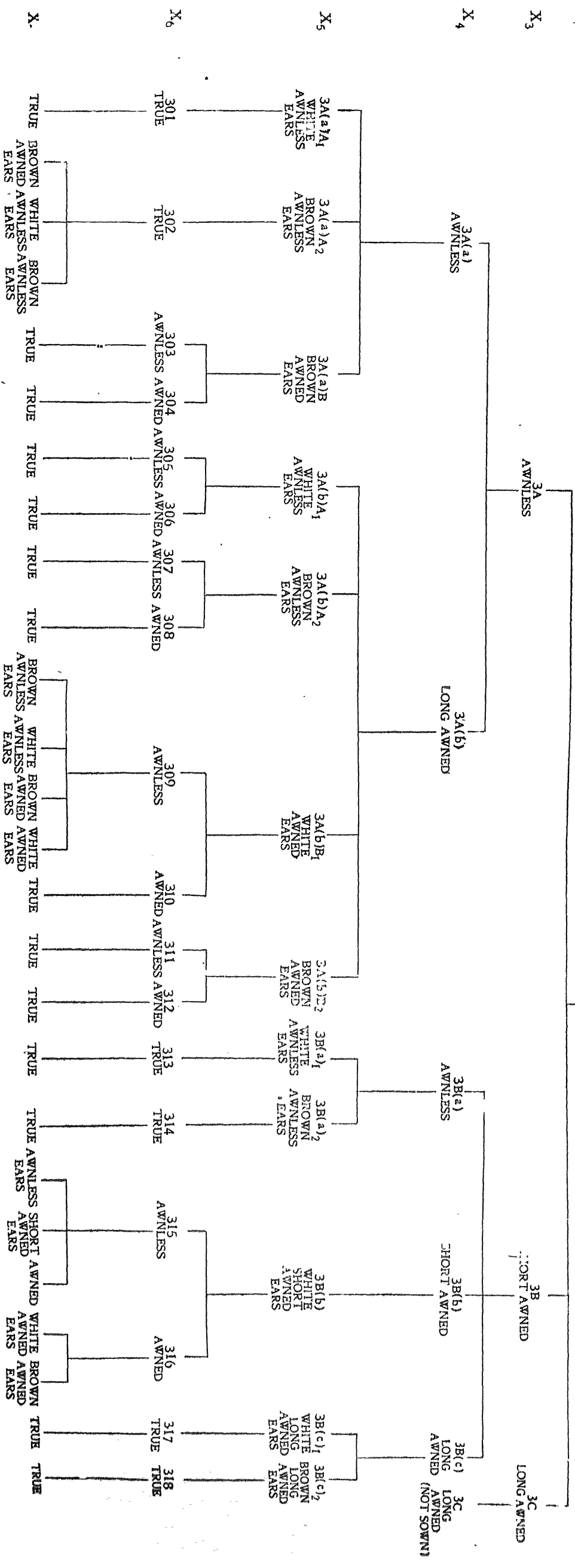


Table No. 2

History of Strain No. R 3

GENERATION

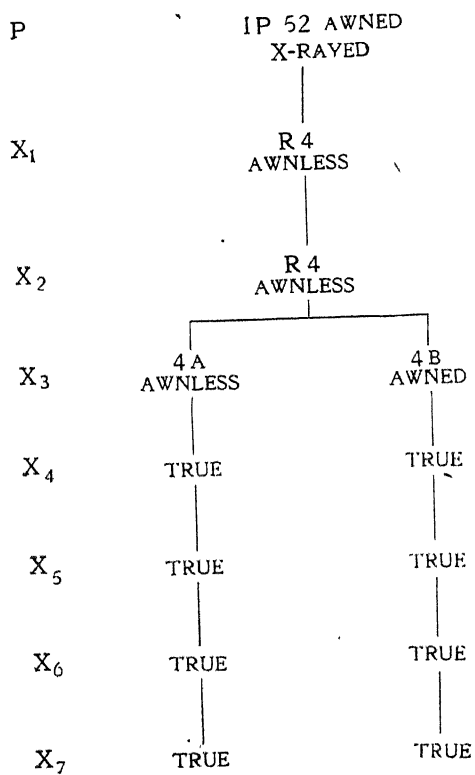


Table No. 3
History of Strain No. R 4

GENERATION

P

IP 52 AWNED
X-RAYED

X₁

R 6 AWNLESS

X₂

R 6 ONLY AWNLESS EARS PICKED

X₃

6A
AWNLESS

6B
SHORT AWNED

6C
LONG AWNED

X₄

6A(a)
AWNLESS

6A(b)
SHORT AWNED

6A(c)
LONG AWNED

6B(a)
AWNLESS

6B(b)
SHORT AWNED

6B(c)
LONG AWNED

6C(a)
AWNED

6C(b)
AWNED

6C(c)
AWNED

X₅

6A(a)A
AWNLESS

6A(a)B
AWNED

6A(b)A
AWNLESS

6A(b)B
AWNED

6A(c)A
AWNLESS

6A(c)B
AWNED

6B(a)A
AWNLESS

6B(a)B
AWNED

6B(b)A
AWNLESS

6B(b)B
AWNED

6B(c)A
AWNLESS

6B(c)B
AWNED

6C(a)A
AWNLESS

6C(a)B
AWNED

6C(b)A
AWNLESS

6C(b)B
AWNED

6C(c)A
AWNLESS

6C(c)B
AWNED

X₆

601
TRUE AWNLESS

602
AWNLESS

603
AWNED

604
AWNLESS

605
AWNED

606
TRUE

607
TRUE

608
TRUE AWNED

609
AWNED

610
AWNLESS

611
AWNLESS AWNED

612
AWNED

613
AWNLESS

614
AWNED

615
TRUE

616
TRUE

617
TRUE

618
TRUE

619
TRUE

620
TRUE

621
TRUE

622
TRUE

623
TRUE

624
TRUE

625
TRUE

X₇

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

TRUE TRUE

Table No. 4

History of Strain No. R 6

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Date of Issue	Date of Issue	Date of Issue
21.5.64	20 JUL 1979	
1.12.64		
4.6.65		
14.12.65		
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97 JUL 1970		
20 JUL 1979		